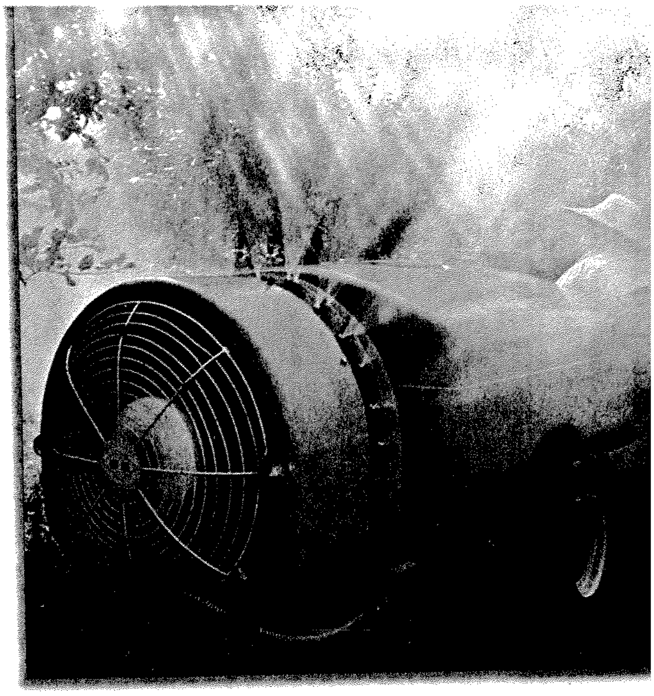
CHAPTER 14



AGRICULTURAL METHODS AND PEST MANAGEMENT

Agricultural use of land results in the modification of the natural world to allow for the growth of crops. Often pest species are controlled with the use of pesticides.

CHAPTER OUTLINE

The Development of Agriculture
- Shifting Agriculture
- Labor-Intensive Agriculture
- Mechanized Agriculture

Fossil Fuel Versus Muscle Power

The Impact of Fertilizer

Agricultural Chemical Use
- Insecticides
- Herbicides
- Fungicides and Rodenticides
- Other Agricultural Chemicals

Problems with Pesticide Use
- Persistence
- Bioaccumulation and Biomagnification
- Pesticide Resistance
- Effects on Nontarget Organisms
- Human Health Concerns

Why Are Pesticides So Widely Used?

Alternatives to Conventional Agriculture
- Sustainable Agriculture
- Techniques for Protecting Soil and Water Resources
- Integrated Pest Management
- Genetically Modified Crops

ISSUES & ANALYSIS
What Does "Certified Organic" Food Mean? 332

CASE STUDIES
DDT—A Historical Perspective 316
Economic Development and Food Production in China 322

CAMPUS SUSTAINABILITY INITIATIVE
Integrated Pest Management at Seattle University 320

GOING GREEN
Organic Farming: Helping to Promote Sustainable Agriculture 325

WATER CONNECTIONS
The Dead Zone of the Gulf of Mexico 319

OBJECTIVES

After reading this chapter, you should be able to:

- Explain how mechanization encouraged monoculture farming.
- List the advantages and disadvantages of monoculture farming.
- Explain why chemical fertilizers are used.
- Understand how fertilizers alter soil characteristics.
- Explain why modern agriculture makes extensive use of pesticides.
- Differentiate between persistent pesticides and nonpersistent pesticides.
- List four problems associated with pesticide use.
- Define biomagnification.
- Define organic farming.
- Explain why integrated pest management depends on a complete knowledge of the pest's life history.
- Recognize that genetically modified crops are created by using biotechnological techniques to insert genes from one species into another.

The following additional Case Studies can be found on the book's website at www.mhhe.com/enger12e along with other interesting readings: "A New Generation of Insecticides," "Industrial Production of Livestock," and "Promoting Environmental Conservation in the Specialty Coffee Industry."

FIGURE 14.1 **Shifting Agriculture** In many areas of the world where the soils are poor and human populations are low, crops can be raised by disturbing small parts of the ecosystem followed by several years of recovery. The burning of vegetation releases nutrients that can be used by crops for one or two years before the soil is exhausted. The return of the natural vegetation prevents erosion and repairs the damage done by temporary agricultural use.

THE DEVELOPMENT OF AGRICULTURE

Our early ancestors obtained food from nature by hunting and gathering. The development of agriculture involved manipulating the natural environment to produce the kinds of foods humans want and allowed for an increase in the size of the human population. The history of the development of agriculture has involved various kinds of innovations. One of the simplest is shifting agriculture, also known as "slash and burn" agriculture.

SHIFTING AGRICULTURE

Shifting agriculture involves cutting down the trees and burning the trees and other vegetation in a small area of the forest. (See figure 14.1.) Burning releases nutrients that were tied up in the biomass and allows a few crops to be raised before the soil is exhausted. Once the soil is no longer suitable for raising crops (within two or three years), the site is abandoned. The surrounding forest recolonizes the area, which will return over time to the original forest through the process of succession.

In some parts of the world with poor soil and low populations, shifting agriculture is still used successfully. This method is particularly useful on thin, nutrient-poor tropical soils and on steep slopes. The small size of the openings in the forest and their temporary existence prevent widespread damage to the soil, and erosion is minimized. While this system of agriculture is successful when human population densities are low, it is not suitable for large, densely populated areas. When populations become too large, the size and number of the garden plots increase and the time between successive uses of the same plot of land decreases. When a large amount of the forest is disturbed and the time between successive uses is decreased, the forest cannot return and repair the damage done by the previous use of the land, and the nature of the forest is changed.

The traditional practices of the people who engage in small-scale, shifting agriculture have been developed over hundreds of years and often are more effective for their local conditions than other methods of gardening. Typically, these gardens are planted with a mixture of plants, a system known as **polyculture.** Mixing plants together in a garden often is beneficial, since shade-requiring species may be helped by taller plants, or nitrogen-fixing legumes may provide nitrogen for species that require it. In addition, mixing species may reduce insect pest problems because some plants produce molecules that are natural insect repellents. The small, isolated, temporary nature of the gardens also reduces the likelihood of insect infestations. While today we see this form of agriculture practiced most commonly in tropical areas, it is important to note that many Native American cultures used shifting agriculture and polyculture in temperate areas.

LABOR-INTENSIVE AGRICULTURE

In many areas of the world with better soils, more intense forms of agriculture developed that involved a great deal of manual labor to till, plant, and harvest the crop. This style of agriculture is still practiced in much of the world today. Three situations favor this kind of farming: (1) when the growing site does not allow for mechanization, (2) when the kind of crop does not allow it, and (3) when the economic condition of the people does not allow them to purchase the tools and machines used for mechanized agriculture. Crops or terrain that requires that fields be small discourages mechanization, since large tractors and other machines cannot be used efficiently on small, oddly shaped fields. Many mountainous areas of the world fit into this category. In addition, some crops require such careful handling in planting, weeding, or harvesting that large amounts of hand labor are required. The planting of paddy rice and the harvesting of many fruits and vegetables are examples. However, the primary reason for labor-intensive farming is economic. Many densely populated countries have numerous small farms of 1 to 2 hectares (a hectare is about the size of a soccer field) that can be effectively managed with human labor, supplemented by that of draft animals and a few small gasoline-powered engines. (See figure 14.2.) In addition, in the less-developed regions of the world, the cost of labor is low, which encourages the use of hand labor rather than relatively expensive machines to do planting, weeding, and other activities.

Mechanization requires large tracts of land that could be accumulated only by the expenditure of large amounts of money or the development of larger cooperative farms from many small units. Even if social and political obstacles to such large landholdings could be overcome, there is still the problem of obtaining the necessary capital to purchase the machines. Large parts of the developing world fit into this category, including much of Africa, many areas in Central and South America, and many areas in Asia. In countries such as China and India, which have a combined population of over 2 billion people, about 70 percent of the population is rural. Many of these people are engaged in nonmechanized agriculture.

MECHANIZED AGRICULTURE

The development of various kinds of machines following the Industrial Revolution resulted in changes in agriculture. Horse-drawn farm implements and the subsequent development of

FIGURE 14.2 Labor-Intensive Agriculture In many of the less-developed countries of the world, the extensive use of hand labor allows for impressive rates of production with a minimal input of fossil fuels and fertilizers. This kind of agriculture is also necessary in areas that have only small patches of land suitable for farming.

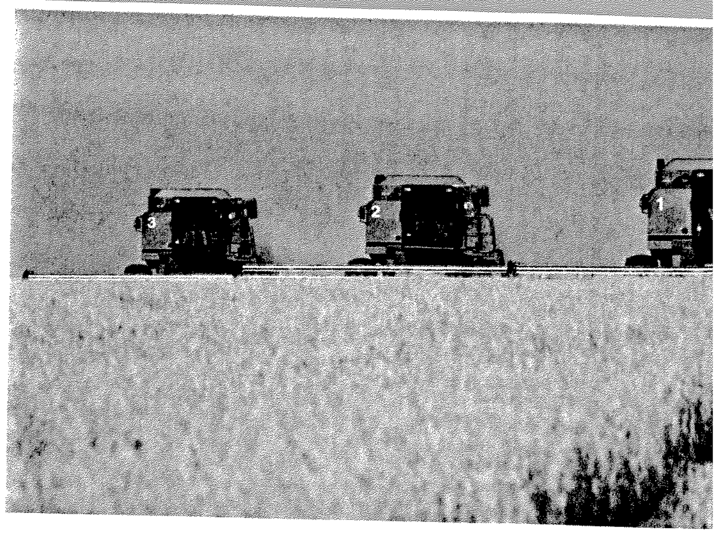


FIGURE 14.3 Mechanized Monoculture This wheat field is an example of monoculture, a kind of agriculture that is highly mechanized and requires large fields for the efficient use of machinery. In this kind of agriculture, machines and fossil-fuel energy have replaced the energy of humans and draft animals.

tractors led to the modern mechanized agriculture typical of North America, much of Europe, and other parts of the world where money and land are available to support this form of agriculture. In large measure, machines and fossil-fuel energy replace the energy formerly supplied by human and animal muscles. Mechanization requires large expanses of fairly level land for the machines to operate effectively. In addition, large tracts of land must be planted in the same crop for efficient planting, cultivating, and harvesting, a practice known as **monoculture.** (See figure 14.3.) Small sections of land with many kinds of crops require many changes of farm machinery, which takes time. Also, many crops interspersed with each other reduces the efficiency of farming operations because farmers must skip parts of the field, which increases travel time and uses expensive fuel.

Even though mechanized monoculture is an efficient method of producing food, it is not without serious drawbacks. When large tracts of land are prepared for planting, they are often left uncovered by vegetation, and soil erosion increases. Because of problems with erosion, many farmers are now using methods that reduce the time the fields are left bare. (See chapter 13.)

Traditionally, mechanized farming has removed much of the organic matter each year when the crop was harvested. This tended to reduce the soil organic matter. As agricultural scientists and farmers have recognized the need to improve the organic-matter content of soils, many farmers have been leaving increased amounts of organic matter after harvest, or they specifically plant a crop that is later plowed under to increase the soil's organic content.

To ensure that a crop can be planted, tended, and harvested efficiently by machines, farmers rely on seeds that are identical genetically and thus provide uniform plants with characteristics suitable for mechanized farming. These special seeds can ensure that all the plants germinate at the same time, resist the same pests, ripen at the same time, and grow to the same height. These are valuable characteristics to the farmer, but these plants have little genetic variety. When all the farmers in an area plant the same genetic varieties, pest control becomes a serious problem. If diseases or pests begin to spread, the magnitude of the problem becomes devastating because all the plants have the same characteristics and, thus, are susceptible to the same diseases. If genetically diverse crops are planted or crops are rotated from year to year, this problem is not as great.

Because farm equipment is expensive, farmers tend to specialize in a few crops. This means that the same crop may be planted in the same field several years in a row. This lack of crop rotation may deplete certain essential soil nutrients, thereby requiring special attention be paid to soil chemistry. In addition, planting the same crop repeatedly encourages the growth of insect and fungus pest populations because they have a huge food supply at their disposal. This requires the frequent use of insecticides and fungicides or other methods of pest control.

Even though there are problems associated with mechanized, monoculture agriculture, it has greatly increased the amount of food available to the world over the past 100 years. Yields per hectare of land being farmed have increased over much of the world, particularly in the developed world, which includes the United States. (See figure 14.4.) This increase has come about because of improved varieties of crops, irrigation, better farming methods, the use of agricultural chemicals, more efficient machines, and the use of energy-intensive as opposed to labor-intensive technology.

Throughout the 1950s, 1960s, and 1970s, the introduction of new plant varieties and farming methods resulted in increased agricultural production worldwide. This has been called the **Green Revolution.** Both the developed world, which uses highly mechanized farming methods, and the developing world, where labor-intensive farming is typical, have benefited from these advances, and food production has increased significantly. The Green Revolution has also had some negative effects. For example, many modern varieties of plants require fertilizer and pesticides that the traditional varieties they replaced did not need. In addition, many of the crops require higher amounts of water and increase the

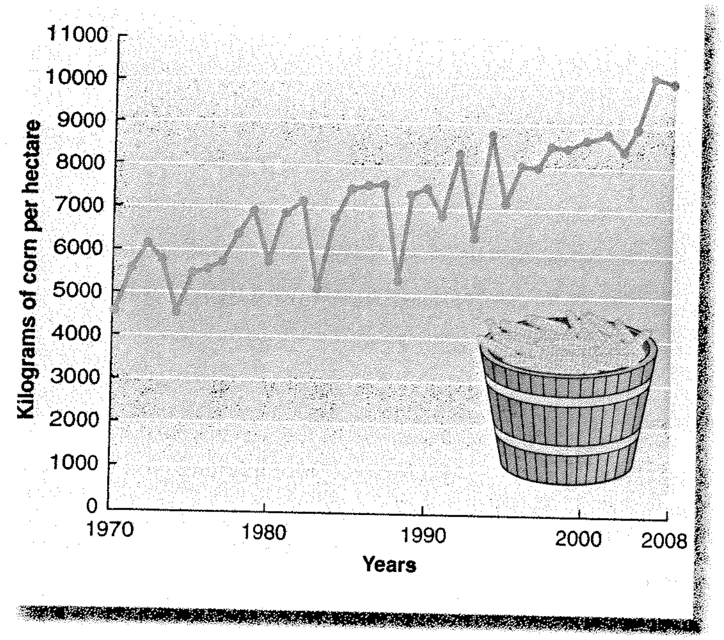


FIGURE 14.4 Increased Yields Resulting from Modern Technology and the Total Amount of Land Available for Cultivation The increased crop yields in the United States and many other parts of the world are the result of a combination of factors, including the development of high-yielding varieties, changed agricultural methods, the application of fertilizers and pesticides, and more efficient machinery.

Sources: Data from U.S. Department of Agriculture, *Agriculture Statistics*, and USDA.

demand for irrigation. Farmers also have become more dependent on the industries that provide the specialized seeds. When the positives and negatives are balanced, however, the end result is that food production per hectare has increased. This has not solved the world's food problem, however, because the population of the world continues to increase and more food is needed.

Long-term solutions to feeding the world's hungry are complex and are unlikely to be found without global answers to problems that have been difficult for decades. These issues include the following:

- Food subsidies and trade barriers—Governments like to protect their farmers with subsidies and trade barriers. Such barriers hinder the development of farming in poorer nations.
- Higher fuel costs—The increase in the price of fuel adds to the cost of food by making it more expensive to produce and transport.
- Alternative fuels—Increased energy prices divert crops to alternative fuels. Growing corn for fuel (and, in many cases, cutting back on wheat production) means less grain for food.
- Rising demand—The rise in global wealth has meant more demand for higher-quality food that is more expensive to produce. In India and China, people are eating more meat. That is a sign of prosperity, but it requires greater supply to sustain. That problem, which also is the major driver behind rising oil prices, is only going to increase.

FOSSIL FUEL VERSUS MUSCLE POWER

Mechanized agriculture has substituted the energy stored in petro leum products for the labor of humans. For example, in th United States in 1913, it required 135 hours of labor to produc 2500 kilograms (5500 pounds) of corn. In 1980, it required onl about 15 hours of labor to produce the same amount of corn. Th energy supplied by petroleum products replaced the equivalent c 120 hours of labor. Energy is needed for tilling, planting, harvesting and pumping irrigation water. The manufacture of fertilizer and pes ticides also requires the input of large amounts of fossil fuels, bot as a source of energy for the industrial process and as raw materia from which these materials are made. For example, about 5 metri tons of fossil fuel are required to produce about 1 metric ton of fer tilizer. In addition, the pesticides used in mechanized agriculture re quire the use of oil as a raw material. Since the developed worl depends on oil to run machines and manufacture fertilizer and pesti cides to support its agriculture, any change in the availability or cos of oil will have a major impact on the world's ability to feed itself.

THE IMPACT OF FERTILIZER

Various experts estimate that approximately 25 percent of the world's crop yield can be directly attributed to the use of chemical fertilizers. The use of fertilizer has increased significantly over the last few decades and is projected to increase even more. (See figure 14.5.) However, since fertilizer production relies on energy from fossil fuels, the price and availability of chemical fertilizers are strongly influenced by world energy prices. If the price of oil increases, the price of fertilizer goes up, as does the cost of food. This is felt most acutely in parts of the world where money is in short supply, since the farmers are unable to buy fertilizer and crop yields fall accordingly.

Fertilizers are valuable because they replace the soil nutrients removed by plants. Some of the chemical building blocks of plants, such as carbon, hydrogen, and oxygen, are easily replaced by carbon dioxide from the air and water from the soil, but others are less easily replaced. The three primary soil nutrients often in short supply are nitrogen, phosphorus, and potassium compounds. They are often referred to as **macronutrients** and are the common ingredient of chemical fertilizers. Their replacement is important because when the crop is harvested, the chemical elements that are a part of the crop are removed from the field. Since many of those elements originated from the soil, they need to be replaced if another crop is to be grown. Certain other elements are necessary in extremely small amounts and are known as **micronutrients.** Examples are boron, zinc, and manganese. As an example of the difference between macronutrients and micronutrients, harvesting 1 metric ton of potatoes removes 10 kilograms (22 pounds) of nitrogen (a macronutrient) but only 13 grams (0.03 pound) of boron (a micronutrient). When the same crop is grown repeatedly in the same field, certain micronutrients may be depleted, resulting in reduced yields. These necessary elements can be returned to the soil in sufficient amounts by incorporating them into the fertilizer the farmer applies to the field.

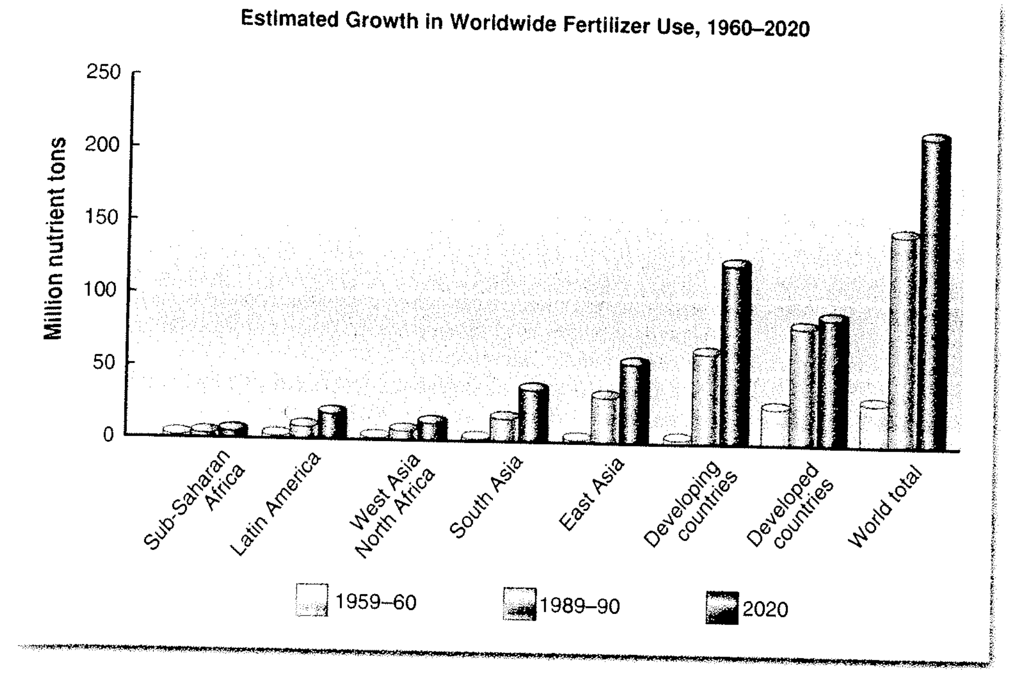


FIGURE 14.5 **Increasing Fertilizer Use** The use of fertilizer is increasing rapidly. Growth in use will be most rapid in the developing countries over the next 20 years.

Although chemical fertilizers replace inorganic nutrients, they do not replace soil organic matter. Organic material is important because it modifies the structure of the soil, preventing compaction and maintaining pore space, which allows water and air to move to the roots. The decomposition of organic matter produces humus, which helps to maintain proper soil chemistry because it tends to loosely bind many soil nutrients and other molecules and modifies the pH so that nutrients are not released too rapidly. Soil bacteria and other organisms use organic matter as a source of energy. Since these organisms serve as important links in the carbon and nitrogen cycles, the presence of organic matter is important to their function. Thus, total dependency on chemical fertilizers usually reduces the amount of organic matter and can change the physical, chemical, and biological properties of the soil.

As water moves through the soil, it dissolves soil nutrients (particularly nitrogen compounds) and carries them into streams and lakes, where they may encourage the growth of unwanted plants and algae. This is particularly true when fertilizers are applied at the wrong time of the year, just before a heavy rain, or in such large amounts that the plants cannot efficiently remove them from the soil before they are lost. These ideas are covered in greater detail in chapter 15 on water management.

AGRICULTURAL CHEMICAL USE

In addition to chemical fertilizers, mechanized monoculture requires large amounts of other agricultural chemicals, such as pesticides, growth regulators, and preservatives. These chemicals have specific scientific names but are usually categorized into broad groups based on their effects. A **pesticide** is any chemical used to kill or control populations of unwanted fungi, animals, or plants, often called **pests.** The term *pest* is not scientific but refers to any organism that is unwanted. Insects that feed on crops are pests, while others, such as bees, are beneficial for pollinating plants. Unwanted plants are generally referred to as **weeds.**

Pesticides can be subdivided into several categories based on the kinds of organisms they are used to control. **Insecticides** are used to control insect populations by killing them. Unwanted fungal pests that can weaken plants or destroy fruits are controlled by **fungicides.** Mice and rats are killed by **rodenticides,** and plant pests (weeds) are controlled by **herbicides.** Since pesticides do not kill just pests but can kill a large variety of living things, including humans, these chemicals might be more appropriately called **biocides.** They kill many kinds of living things. A perfect pesticide is one that kills or inhibits the growth of only the specific pest organism causing a problem. The pest is often referred to as the **target organism.** However, most pesticides are not very specific and kill many **nontarget organisms** as well. For example, most insecticides kill both beneficial and pest species, rodenticides kill other animals as well as rodents, and most herbicides kill a variety of plants, both pests and nonpests.

Many of the older pesticides were very stable and remained active for long periods of time. These are called **persistent pesticides.** Pesticides that break down quickly are called **nonpersistent pesticides.**

INSECTICIDES

If insects are not controlled, they consume a large proportion of the crops produced by farmers. In small garden plots, insects can be controlled by manually removing them and killing them. However, in large fields, this is not practical, so people have sought other ways to control pest insects.

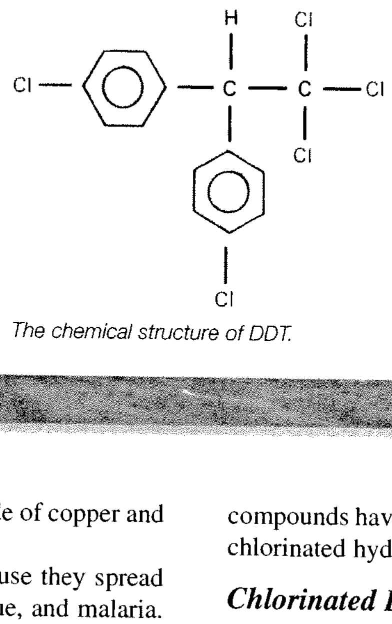
Nearly 3000 years ago, the Greek poet Homer mentioned the use of sulfur to control insects. For centuries, it was known that natural plant products could repel or kill insect pests. Plants with insect-repelling abilities were interplanted with crops to help control the pests. Nicotine from tobacco, rotenone from tropical legumes, and pyrethrum from chrysanthemums were extracted and used to control insects. In fact, these compounds are still used today. However, because plant products are difficult to extract and apply and have short-lived effects, other compounds were sought. In 1867, the first synthetic inorganic insecticide, Paris green, was

CASE STUDY 14.1

DDT—A HISTORICAL PERSPECTIVE

The first synthetic organic insecticide to be used was DDT [1,1,1-trichloro-2,2-*bis*-(p-chlorophenyl)ethane] (see the figure). DDT was originally thought to be the perfect insecticide. It was inexpensive, long-lasting, relatively harmless to humans, and very deadly to insects. After its discovery, it was widely used in agriculture and to control disease-carrying insects. During the first 10 years of its use (1942–52), DDT is estimated to have saved 5 million lives, primarily because of its use in controlling disease-carrying mosquitoes.

However, DDT had several drawbacks. Although most of these drawbacks are not unique to DDT, they were first recognized with DDT because it was the first widely used insecticide. One problem involved the development of resistance in insect populations that were repeatedly subjected to spraying by DDT. Another was the fact that it affected many nontarget organisms, not just the disease-carrying insects that were the original targets. This was a particular problem because DDT is a persistent chemical, which is another major drawback. In temperate regions of the world, DDT has a half-life (the amount of time required for half of the chemical to decompose) of 10 to 15 years. This means that if 1000 kilograms (2200 pounds) of DDT were sprayed over an area, 500 kilograms (1100 pounds) would still be present in the area 10 to 15 years later; 30 years from the date of application, 250 kilograms (550 pounds) would still be present. The half-life of DDT varies depending on soil type, temperature, the kinds of soil organisms present, and other factors. In tropical parts of the world, the half-life may be as short as six months. An additional complication is that persistent pesticides may break down into products that are still harmful. Furthermore, because it is persistent, DDT tends to accumulate and reach higher concentrations in older animals and in animals at higher trophic levels.



The chemical structure of DDT.

When these effects were recognized, the United States and mar other developed countries banned the use of DDT. A key force in brin ing about this change in thinking was the book *Silent Spring,* by Rach Carson. (See Case Study: Early Philosophers of Nature in chapter 2.) Th results of this ban are clearly seen in the reduced levels of DDT in the er vironment and in the recovery of populations of such organisms as ea gles, cormorants, and pelicans.

Because of these problems, the World Wildlife Fund asked dele gates at a United Nations Environment Programme conference c persistent organic pollutants in 1999 to ban DDT from use througho the world because it was showing up worldwide in the bodies of mar kinds of animals that were great distances from sources of DDT an was present in the breast milk of women where DDT is used. This re sulted in a great deal of protest from public health people concerne about controlling malaria, since DDT is still widely used in many part of the world, where it is sprayed on the walls of houses to kill mosqu toes that spread malaria. The use of DDT is still effective and is muc less expensive than materials that would be substituted for it. The feared that the total ban of DDT would result in les effective control of mosquitoes and increase deaths from malaria. Where the risk of dying fror malaria is high and the risk of possible health effect from exposure to DDT is low, it makes sense to us an inexpensive, effective material such as DDT. I countries where malaria and other serious insect transmitted diseases are rare (most of the devel oped world), it is possible to eliminate the use c DDT. Ultimately, continued use of DDT was sanc tioned for the control of malaria and other disease transmitted by insects, and it continues to be use for these purposes today.

formulated. It was a mixture of acetate and arsenide of copper and was used to control Colorado potato beetles.

In addition, many insects harm humans because they spread diseases, such as sleeping sickness, bubonic plague, and malaria. Mosquitoes are known to carry over 30 diseases harmful to humans. Currently, the World Health Organization estimates that between 300 million and 500 million people have malaria and 1.1 million people die of the disease each year. Most of these deaths are children. Malaria is one of the top five causes of death in children. The discovery of chemicals that could kill insects was celebrated as a major advance in the control of disease and the protection of crops.

DDT was the first synthetic organic insecticide produced. (See Case Study: DDT—A Historical Perspective.) Since then, over 60,000 different compounds that have potential as insecticides have been synthesized. However, most of these have never been put into production because cost, human health effects, or other drawbacks make them unusable. Several categories of these compounds have been developed. Three that are currently used ar chlorinated hydrocarbons, organophosphates, and carbamates.

Chlorinated Hydrocarbons

Chlorinated hydrocarbons are a group of pesticides of complex stable structure that contain carbon, hydrogen, and chlorine. DDT was the first such pesticide manufactured, but several others have been developed. Other chlorinated hydrocarbons are chlordane aldrin, heptachlor, dieldrin, and endrin. It is not fully understood how these compounds work, but they are believed to affect the nervous systems of insects, resulting in their death.

One of the major characteristics of these pesticides is that they are very stable chemical compounds. This is both an advantage and a disadvantage. They can be applied once and be effective for a long time. However, since they do not break down easily, they tend to accumulate in the soil and in the bodies of animals in the food chain. Thus, they affect many nontarget organisms, not just the original target insects.

Because of their negative effects, most of the chlorinated hydrocarbons are no longer used in many parts of the world. DDT, aldrin, dieldrin, toxaphene, chlordane, and heptachlor have been banned in the United States and many other developed countries. However, many developing countries still use chlorinated hydrocarbons for insect control to protect crops and public health. Because of their persistence and continued use in many parts of the world, chlorinated hydrocarbons are still present in the food chain, although the level of contamination has dropped. These molecules continue to enter parts of the world where their use has been banned through the atmosphere and as trace contaminants of imported products.

Organophosphates and Carbamates

Because of the problems associated with persistent insecticides, nonpersistent insecticides that decompose to harmless products in a few hours or days were developed. However, like other insecticides, these are not species-specific; they kill beneficial insects as well as harmful ones. Although the short half-life prevents the accumulation of toxic material in the environment, it is a disadvantage for farmers, since more frequent applications are required to control pests. This requires more labor and fuel and, therefore, is more expensive.

Both **organophosphates** and **carbamates** work by interfering with the ability of the nervous system to conduct impulses normally. Under normal conditions, a nerve impulse is conducted from one nerve cell to another by means of a chemical known as a neurotransmitter. One of the most common neurotransmitters is acetylcholine. When this chemical is produced at the end of one nerve cell, it causes an impulse to be passed to the next cell, thereby transferring the nerve message. As soon as this transfer is completed, an enzyme known as cholinesterase destroys acetylcholine, so the second nerve cell in the chain is stimulated for only a short time. Organophosphates and carbamates interfere with cholinesterase, preventing it from destroying acetylcholine. This results in nerve cells being continuously stimulated, causing uncontrolled spasms of nervous activity and uncoordination that result in death.

Although these pesticides are less persistent in the environment than are chlorinated hydrocarbons, they are generally much more toxic to humans and other vertebrates because these insecticides affect their nerve cells as well. Persons who apply such pesticides must use special equipment and should receive special training because improper use can result in death. Since organophosphates interfere with cholinesterase more strongly than do carbamates, they are considered more dangerous and, for many applications, have been replaced by carbamates.

Common organophosphates are malathion, parathion, and diazinon. Malathion is widely used for such projects as mosquito control, but parathion is a restricted organophosphate because of its high toxicity to humans. Diazinon is widely used in gardens. Carbaryl, propoxur, and aldicarb are examples of carbamates. Carbaryl (Sevin) is widely used in home gardens and in agriculture to control many kinds of insects. Propoxur is not used on crops but is used to control insects around homes and farms. Aldicarb is a restricted-use insecticide that is used primarily on cotton, soybeans, and peanuts. It has been associated with groundwater contamination and has been discontinued for some uses, such as control of insects in potatoes.

Herbicides

Herbicides are another major class of chemical control agents. I fact, about 60 percent of the approximately 440 million kilogram (about 1 billion pounds) of pesticides used in U.S. agriculture ar herbicides. They are widely used to control unwanted vegetatio along power-line rights-of-way, railroad rights-of-way, and high ways, as well as on lawns and cropland, where they are commonl referred to as weed killers.

Weeds are plants we do not want to have growing in a particular place. Weed control is extremely important for agriculture be cause weeds take nutrients and water from the soil, making then unavailable to the crop species. In addition, weeds may shade the crop species and prevent it from getting the sunlight it needs for rapic growth. At harvest time, weeds reduce the efficiency of harvesting machines. Also, weeds generally must be sorted from the crop before it can be sold, which adds to the time and expense of harvesting.

Traditionally, farmers have expended much energy trying to control weeds. Initially, weeds were eliminated with manual labor and the hoe. Tilling the soil also helps to control weeds. Once the crop is planted, row crops such as corn or sugar beets may be cultivated to remove weeds from between the rows. All of these activities are expensive in terms of time and fuel. Selective use of herbicides can have a tremendous impact on a farmer's profits.

Many of the recently developed herbicides can be very selective if used appropriately. Some are used to kill weed seeds in the soil before the crop is planted, while others are used after the weeds and the crop begin to grow. In some cases, a mixture of herbicides can be used to control several weed species simultaneously. Figure 14.6 shows the effects of using a herbicide that kills grasses but not other kinds of plants.

Several major types of herbicides are in current use. One type is synthetic plant-growth regulators that mimic natural-growth regulators known as **auxins.** Two of the earliest herbicides were of this

FIGURE 14.6 The Effect of Herbicides The grasses in this photograph have been treated with herbicides. The soybeans are unaffected and grow better without competition from grasses.

type: 2,4-dichlorophenoxyacetic acid (2,4-D) and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T). When applied to broadleaf plants, these chemicals disrupt normal growth, causing the death of the plant. 2,4-D has been in use for about 50 years and is still one of the most widely used herbicides. Many newer herbicides have other methods of action. Some disrupt the photosynthetic activity of plants, causing their death. Others inhibit enzymes, precipitate proteins, stop cell division, or destroy cells directly. Depending on the concentration of the herbicide used, some are toxic to all plants, while others are very selective as to which species of plants they affect. One such herbicide is diuron. In proper concentrations and when applied at the appropriate time, it can be used to control annual grasses and broadleaf weeds in over 20 different crops. However, at higher concentrations, it kills all vegetation in an area. Fenuron is an herbicide that kills woody plants. In low concentration, it is used to control woody weed plants in cropland. In high concentrations, it is used on noncroplands, such as power-line rights-of-way. (See figure 14.7.)

Atrazine is widely used to control broad-leaf and grassy weeds in corn, sorghum, sugarcane, pineapple, Christmas trees, and other crops, and in conifer reforestation plantings. Glyphosate is a broad-spectrum, nonselective, systemic herbicide used to control annual and perennial plants, including grasses, sedges, broad-leaved weeds, and woody plants. It can be used on noncropland as well as on a great variety of crops.

Fungicides and Rodenticides

Fungus pests can be divided into two categories. Some are natural decomposers of organic material, but when the organic material being destroyed happens to be a crop or other product useful to humans, the fungus is considered a pest. Other fungi are parasites on crop plants; they weaken or kill the plants, thereby reducing the yield. Fungicides are used as fumigants (gases) to protect agricultural products from spoilage, as sprays and dusts to prevent the spread of diseases among plants, and as seed treatments to protect seeds from rotting in the soil before they have a chance to germinate. Methylmercury is often used on seeds to protect them from spoilage before germination. However, since methylmercury is extremely toxic to humans, these seeds should never be used for food. To reduce the chance of a mix-up, treated seeds are usually dyed a bright color.

Like fungi, rodents are harmful because they destroy food supplies. In addition, they can carry disease and damage crops in the field. In many parts of the world, such as India, the government pays a bounty to people who kill rats, because this is an inexpensive way to protect the food supply. Several kinds of rodenticides have been developed to control rodents. One of the most widely used is warfarin, a chemical that causes internal bleeding in animals that consume it. It is usually incorporated into a food substance so that rodents eat warfarin along with the bait. Because it is effective in all mammals, including humans, it must be used with care to prevent nontarget animals from having access to the chemical. As with many kinds of pesticides, some populations of rodents have become tolerant of warfarin, while others avoid baited areas. In many cases, rodent problems can be minimized by building storage buildings that are rodent-proof, rather than relying on rodenticides.

Other Agricultural Chemicals

In addition to herbicides, other agrochemicals are used for special applications. For example, a synthetic auxin sprayed on cotton plants before harvest causes the leaves to drop off, which facilitates the harvesting process by reducing clogging of the mechanical cotton picker.

NAA (naphthaleneacetic acid) is used by fruit growers to prevent apples from dropping from the trees and being damaged. This chemical can keep the apples on the trees for up to 10 extra days, which allows for a longer harvest period and fewer lost apples.

Under other conditions, it may be valuable to get fruit to fall more easily. Cherry growers use ethephon to promote loosening of the fruit so that the cherries will fall more easily from the tree when shaken by the mechanical harvester. This method lowers the cost of harvesting the fruit. (See figure 14.8.)

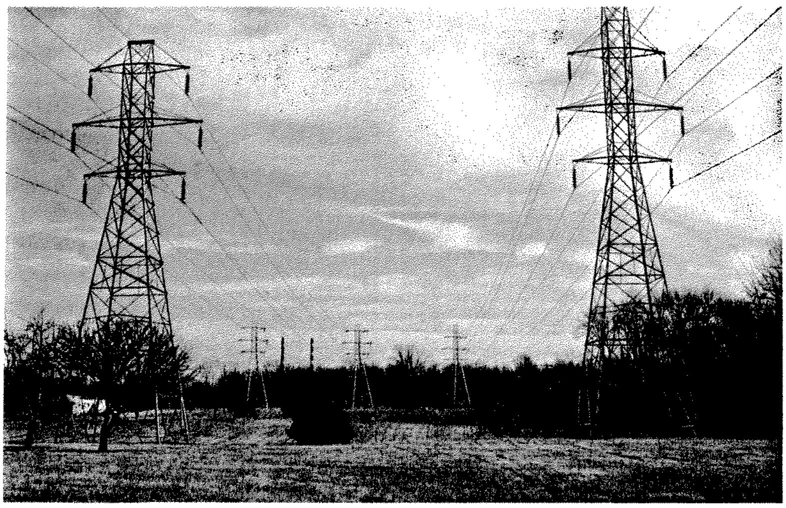


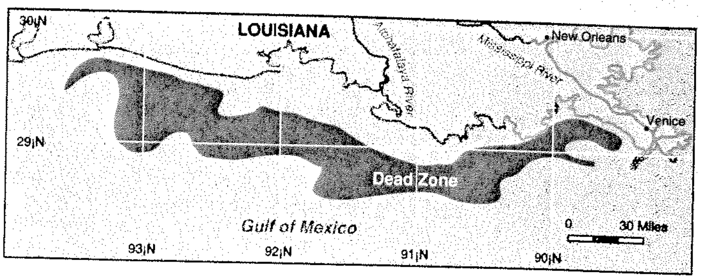
FIGURE 14.7 Herbicide Use to Maintain Rights-of-Way Power-line rights-of-way are commonly maintained by herbicides that kill the woody vegetation, which might grow so tall that it interferes with the power lines.

FIGURE 14.8 Chemical Loosening of Cherries to Allow Mechanical Harvesting By using chemicals and machinery, this farmer can rapidly harvest the cherry crop. This practice reduces the amount of labor required to pick the cherries but requires the application of chemicals to loosen the fruit.

Water Connections

The Dead Zone of the Gulf of Mexico

Each summer, a major "dead zone" of about 18,000 square kilometers (7000 square miles) develops in the Gulf of Mexico off the mouth of the Mississippi River. This dead zone contains few fish and bottom-dwelling organisms. It is caused by low oxygen levels (hypoxia) brought about by the rapid growth of algae and bacteria in the nutrient-rich waters. The nutrients can be traced to the extensive use of fertilizer in the major farming areas of the central United States, farming areas drained by the Mississippi River and its tributaries. About 1.6 million metric tons of nitrogen—mostly fertilizer runoff from midwestern farms—flows out of the Mississippi River every year.



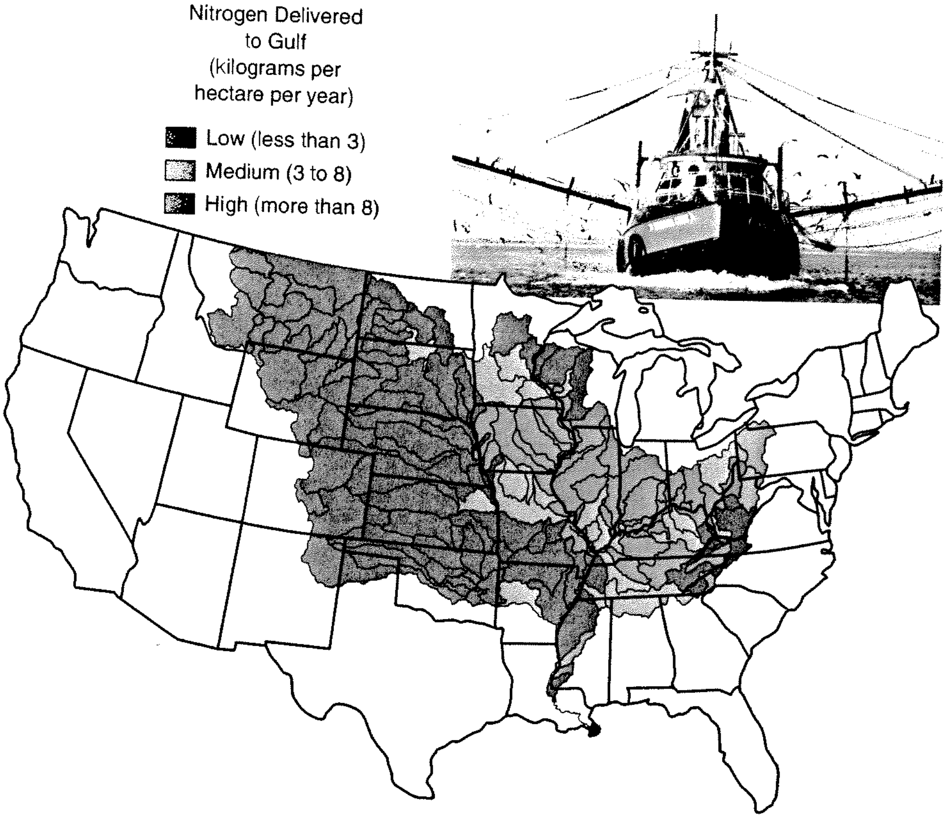
The hypoxia problem begins when nitrogen and other nutrients wash down the Mississippi River to the Gulf of Mexico, where they trigger a bloom of microscopic plants and animals. The dead cells and fecal matter of the organisms then fall to the seafloor. As growing colonies of bacteria digest this waste, they consume dissolved oxygen faster than it can be replenished. The flow of oxygen-rich water from the Mississippi cannot rectify the problem, because differences in temperature and density cause the warm freshwater to float above the colder, salty ocean water. Crustaceans, worms, and any other animals that cannot swim out of the hypoxic zone die.

According to the EPA, nutrient pollution has degraded more than half of U.S. estuaries. In 2002, the National Research Council named nutrient pollution and the sustainability of fisheries as the most important problems facing the U.S. coastal waters in the next decade.

Gulf of Mexico fisheries, which generate some $2.8 billion a year in revenue, are one potential casualty of hypoxia. Hypoxia can block crucial migration of shrimp, which must move from inland nurseries to feed and spawn offshore. In other places in the world, such as the Black and Baltic Seas, hypoxia has been responsible for the collapse of some commercial fisheries.

Several approaches could reduce the amount of hypoxia-causing nitrogen released into the Mississippi River Basin. These include:

- Reduce use of nitrogen-based fertilizers and improve storage of manure. Reduce runoff from feedlots.
- Plant perennial crops instead of fertilizer-intensive corn and soybeans on 10 percent of the acreage.
- Remove nitrogen and phosphorus from domestic wastewater.
- Restore 2 million to 4 million hectares (5–10 million acres) of wetlands, which absorb nitrogen runoff.



Source: Reprinted by permission from Macmillan Publishers Ltd: *Nature*, 403; 761, Effect of stream channel size on the delivery of nitrogen to the Gulf of Mexico, copyright © 2000.

Source: Dead Zone map modified from R. B. Alexander, R. A. Smith, and G. E. Schwartz, "Effect of Stream Channel Size on the Delivery of Nitrogen to the Gulf of Mexico," *Nature*, 17 (February 2000): 761.

CAMPUS SUSTAINABILITY INITIATIVE

INTEGRATED PEST MANAGEMENT AT SEATTLE UNIVERSITY

Seattle University differs from many other campuses by rejecting the notion that pesticide application is a viable last resort in dealing with harmful insects and disease infestation on university grounds. A shift to sustainable landscape practices began in 1979 with the adoption of an Integrated Pest Management (IPM) program. The Grounds Department has successfully and beautifully maintained the campus since 1986 without the use of pesticides. The main components of Seattle University's IPM program include the following:

- Mechanical—removal or disruption of pests using various traps and tools
- Cultural—planting plants of different species that are naturally disease or insect resistant
- Biological—release of beneficial insects that prey on harmful pests
- Chemical—use of compounds (i.e., insecticidal soaps, compost tea, vinegar, and citric acid)

In addition, plants for use on the campus are chosen that need little water, are well suited to the northwest climate, resist insect and disease infestation, and are not invasive species that out-compete native species. Selecting combinations of plants that meet these criteria and are also aesthetically pleasing, low maintenance, affordable, and contribute to the creation of wildlife habitat is a subjective and sometimes difficult process that the university gardeners work hard to achieve.

PROBLEMS WITH PESTICIDE USE

A perfect pesticide would have the following characteristics:

1. It would be inexpensive.
2. It would affect only the target organism.
3. It would have a short half-life.
4. It would break down into harmless materials.

However, the perfect pesticide has not been invented. Many of the more recently developed pesticides have fewer drawbacks than the early pesticides, but none is without problems.

PERSISTENCE

Although the trend has been away from using persistent pesticides in North America and much of the developed world, some are still allowed for special purposes, and they are still in common use in other parts of the world. Because of their stability, these chemicals have become a long-term problem. Persistent pesticides become attached to small soil particles, which are easily moved by wind or water to any part of the world. Persistent pesticides and other pollutants have been discovered in the ice of the poles and are present in detectable amounts in the body tissues of animals, including humans, throughout the world. Thus, chemicals originally sprayed to control mosquitoes in Africa or to protect a sugarcane field in Brazil may be distributed throughout the world.

BIOACCUMULATION AND BIOMAGNIFICATION

A problem associated with persistent chemicals is that they may accumulate in the bodies of animals. If an animal receives small quantities of persistent pesticides or other persistent pollutants in its food and is unable to eliminate them, the concentration within the animal increases. This process of accumulating higher and higher amounts of material within the body of an animal is called **bioaccumulation.** Many of the persistent pesticides and their breakdown products are fat soluble and build up in the fat of animals. When affected animals are eaten by a carnivore, these toxins are further concentrated in the body of the carnivore, causing disease or death, even though lower-trophic-level organisms are not injured. This phenomenon of acquiring increasing levels of a substance in the bodies of higher-trophic-level organisms is known as **biomagnification.**

The well-documented case of DDT is an example of how biomagnification occurs. DDT is not very soluble in water but dissolves in oil or fatty compounds. When DDT falls on an insect or is consumed by the insect, the DDT is accumulated in the insect's fatty tissue. Large doses kill insects but small doses do not, and their bodies may contain as much as one part per billion of DDT. This is not very much, but it can have a tremendous effect on the animals that feed on the insects.

If an aquatic habitat is sprayed with a small concentration of DDT or receives DDT from runoff, small aquatic organisms may accumulate a concentration that is up to 250 times greater than the concentration of DDT in the surrounding water. These organisms

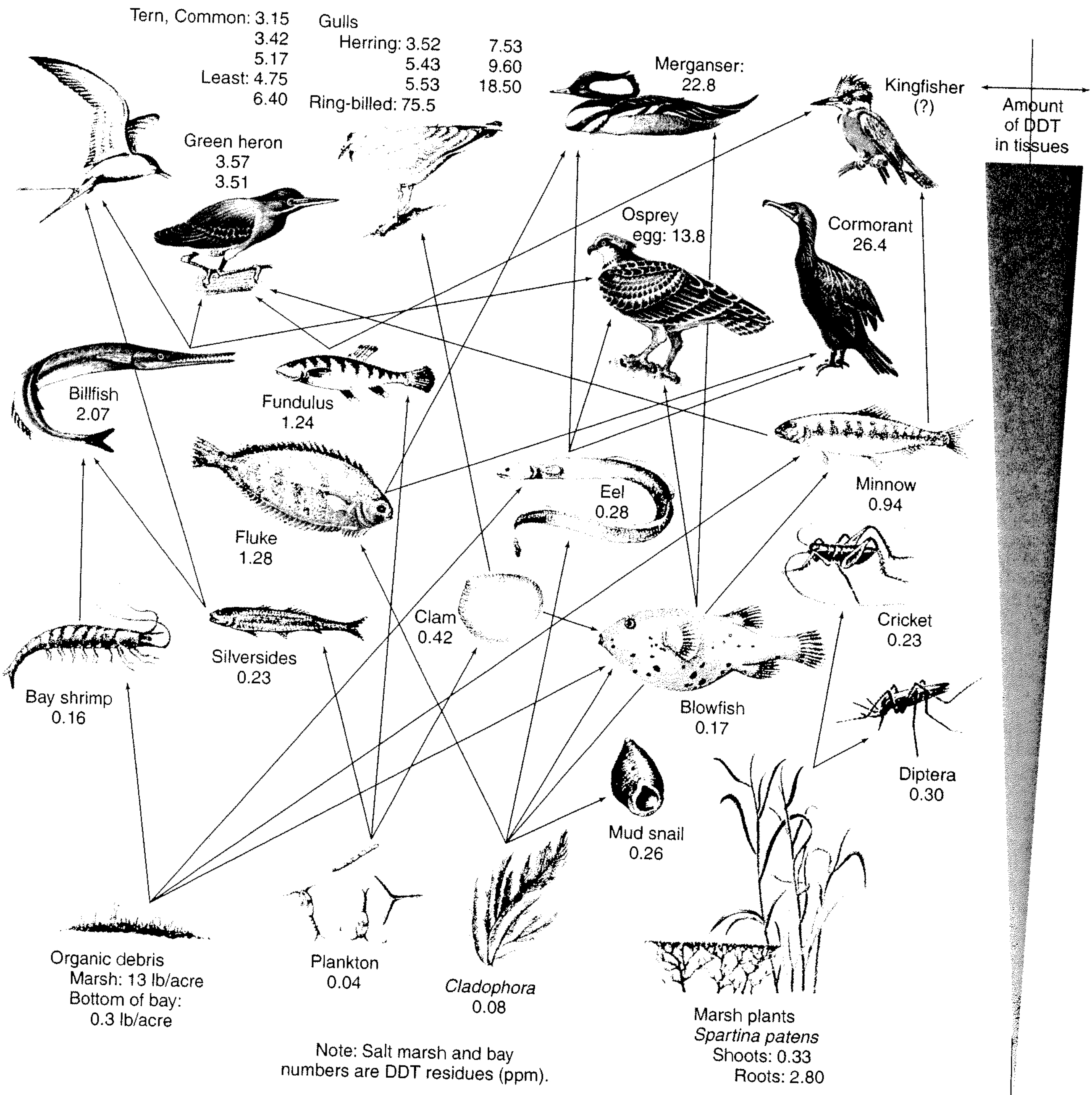


FIGURE 14.9 The Biomagnification of DDT All the numbers shown are in parts per million (ppm). A concentration of one part per million means that in a million equal parts of the organism, one of the parts would be DDT. Notice how the amount of DDT in the bodies of the organisms increases as we go from producers to herbivores to carnivores. Because DDT is persistent, it builds up in the top trophic levels of the food chain.

are eaten by shrimp, clams, and small fish, which are, in turn, eaten by larger fish. DDT concentrations of large fish can be as much as 2000 times the original concentration sprayed on the area. What was a very small initial concentration has now become so high that it could be fatal to animals at higher trophic levels. This has been of particular concern for birds, since DDT interferes with the production of eggshells, making them much more fragile. This problem is more common in carnivorous birds because they are at the top of the food chain. Although all birds of prey have probably been affected to some degree, those that rely on fish for food seem to have been affected most severely. Eagles, osprey, cormorants, and pelicans are particularly susceptible species. (See figure 14.9.)

Other persistent molecules are known to behave in similar fashion. Mercury, aldrin, chlordane, and other chlorinated hydrocarbons, such as polychlorinated biphenyls (PCBs) used as insulators in electric transformers, are all known to accumulate in ecosystems. PCBs have been strongly implicated in the decline of cormorants in the Great Lakes. As PCB levels have declined, the cormorant population has returned to former levels.

CASE STUDY 14.2

ECONOMIC DEVELOPMENT AND FOOD PRODUCTION IN CHINA

When the economic conditions of a people improve, the change is reflected in the quality of their diet. In particular, meat becomes a bigger part of the diet. Therefore, people feed some of their grains to animals and consume animal products such as meat, fish, eggs, and butter. They eat more vegetables and use more edible oils. In short, they move a bit higher up the food chain.

A sizable percentage of China's nearly 1.3 billion citizens are moving up the food chain. In the early 1980s, the typical urban Chinese diet consisted of rice, porridge, and cabbage. By the middle 1990s, the diet had dramatically changed to include meat, eggs, or fish at least once a day.

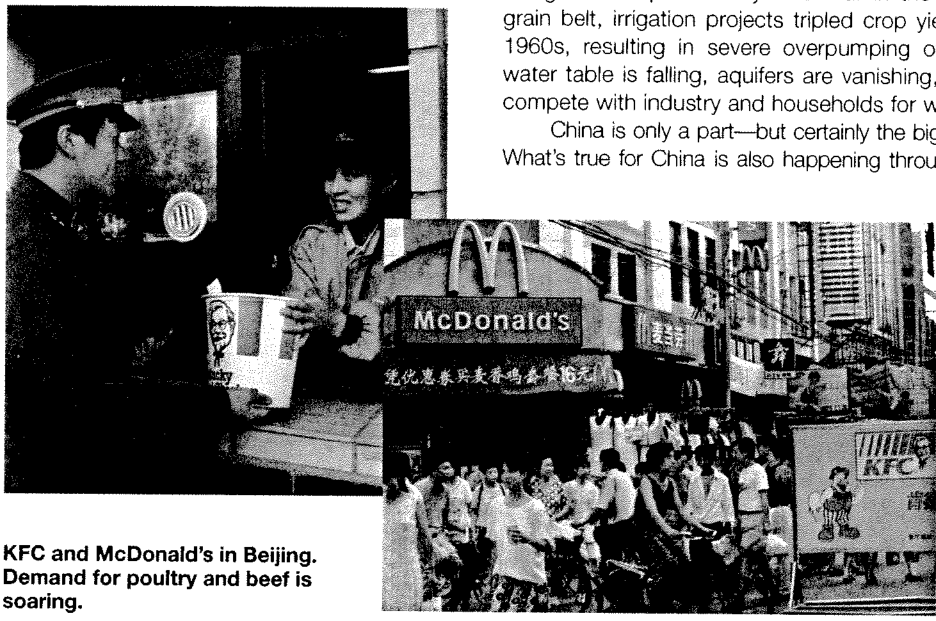
China has about 21 percent of the world's population but only 7 percent of the arable land; in other words, it has less arable land than the United States but nearly five times the population. China's farm sector is simply unable to keep up with the surging demand for what people regard as better food.

Total meat consumption in China is growing by 10 percent a year; feed for animal consumption is growing by 15 percent. Demand for poultry, which requires 2 to 3 kilograms of feed per kilogram of bird, has doubled in five years. China's new diet will make it more dependent on the United States, Canada, and Australia for feed grains. By 1997, China had gone from being a net exporter of grain to importing 16 million metric tons. The switch in corn is even more dramatic. As recently as 1995, China was the second-largest corn exporter in the world. But with the chickens and pigs eating so much corn, in one year, China moved from exporting 12 million metric tons of corn to importing 4 million metric tons.

To support its increased agricultural needs, China has become the world's largest importer of fertilizer. In addition, the government is converting some marginal lands in the north for agriculture. Even so, its farmland is declining by at least 0.5 percent per year because of the loss of fertile, multiple-cropped farmland in the southern coastal provinces.

As in much of the world, irrigation is responsible for a major portion of agricultural productivity in China. In the Yellow River Valley's large grain belt, irrigation projects tripled crop yields during the 1950s and 1960s, resulting in severe overpumping of groundwater. Today, the water table is falling, aquifers are vanishing, and farmers now have to compete with industry and households for water.

China is only a part—but certainly the biggest part—of a larger story. What's true for China is also happening throughout much of Asia. Large populous countries such as Indonesia, Thailand and the Philippines are rapidly urbanizing. They are gaining purchasing power and losing farmland, and the people are adding more animal proteins and processed foods to their diets. Given the magnitude of the changes, the world's ability to feed itself in the future is difficult to predict.



KFC and McDonald's in Beijing. Demand for poultry and beef is soaring.

Because of their persistence, their effects on organisms at higher trophic levels, and concerns about long-term human health problems, most chlorinated hydrocarbon pesticides have been banned from use in the United States and some other countries. The use of DDT was prohibited in the United States in the early 1970s. Aldrin, dieldrin, heptachlor and chlordane have also been prohibited from use on crops, although heptachlor and chlordane were still used for termite control until recently. In 1987, Velsicol Chemical Corporation agreed to stop selling chlordane in the United States.

The populations of several species of birds, including the brown pelican, bald eagle, osprey, and cormorant, all of which feed primarily on fish, were severely affected because of biomagnification of persistent organic chemicals. With the control or restriction of most persistent pesticides and several other chemicals, the levels of these chemicals in their body tissues have declined, and their populations have rebounded. The bald eagle has been removed from the endangered species list, and the pelican has been removed from the endangered species list in part of its range.

PESTICIDE RESISTANCE

Another problem associated with pesticides is the ability of pest populations (insects, weeds, rodents, fungi) to become resistant to them. Pesticide resistance develops because not all organisms within

a given species are identical. Each individual has a slightly different genetic composition and slightly different characteristics. If an insecticide is used for the first time on the population of a particular insect pest, it kills all the individuals that are susceptible. Individuals with characteristics that allow them to tolerate the insecticides may live to reproduce.

If only 5 percent of the individuals possess genes that make them resistant to an insecticide, the first application of the insecticide will kill 95 percent of the exposed population and so will be of great benefit in controlling the size of the insect population. However, the surviving individuals that are tolerant of the insecticide will constitute the majority of the breeding populations. Since these individuals possess genetic characteristics for tolerating the insecticide, so will many of their offspring. Therefore, in the next generation, the number of individuals able to tolerate the insecticide will increase, and the second use of the insecticide will not be as effective as the first. Since some species of insect pests can produce a new generation each month, this process of selecting individuals capable of tolerating the insecticide can result in resistant populations in which 99 percent of the individuals are able to tolerate the insecticide within five years. As a result, that particular insecticide is no longer as effective in controlling insect pests, and increased dosages or more frequent spraying may be necessary. Over 500 species of insects have populations resistant to insecticides.

For example, a study of insecticide resistance of houseflies in poultry facilities used for egg production shows that these populations of houseflies are resistant to a wide variety of insecticides compared to a nonresistant test population. Poultry facilities are an excellent situation for developing resistance, since the flies spend their entire lives within the facility and are subjected to repeated applications of insecticide. Table 14.1 shows the effect of the insecticide Cyfluthrin on resistance in a particular housefly population. The standard dose that killed susceptible houseflies did not kill the resistant population. Even at a dosage of 100 times the standard dose, nearly 40 percent of the houseflies in the resis-tant population survived.

Effects on Nontarget Organisms

Most pesticides are not specific and kill beneficial species as well as pest species. With herbicides, this is usually not a problem because an herbicide is chosen that does not harm the desired crop plant, and generally all other plants are competing pests. However, with insecticides, several problems are associated with the effects ‹ nontarget organisms. The use of insecticides can harm populatio of birds, mammals, and harmless or beneficial insects. In gener insecticides that harm vertebrates are restricted in their us However, it is difficult to apply insecticides in such a way that on the harmful species are affected. When beneficial insects are kill by insecticides, pesticide use can be counterproductive. If an i secticide kills predator and parasitic insects that normally contr the pest insects, there are no natural checks to control the popul tion growth of the pest species. Additional applications of insect cides are necessary to prevent the pest population from reboundir to levels even higher than the initial one. Once the decision made to use pesticides, it often becomes an irreversible tactic, b cause stopping their use would result in rapid increases in pe populations and extensive crop damage.

An associated problem is that the use of insecticides ma change the population structures of the species present so that species that was not previously a problem becomes a serious pes For example, when synthetic organic insecticides came into com mon use with cotton in the 1940s, the insect parasites and preda tors were eliminated, and the bollworm and tobacco budworr became major pests. In the mid-1990s, a similar situation devel oped when repeated use of malathion removed predator insect and allowed beet army worms to become a major pest. Th repeated use of insecticides caused a different pest problem t develop.

Human Health Concerns

Short-term and long-term health effects to persons applying pesticides and the public that consumes pesticide residues in food are also concerns. If properly applied, most pesticides can be usec with little danger to the applicator. However, in many cases, people applying pesticides are unaware of how they work and wha precautions should be used in their application. In many parts of the world, farmers may not be able to read the caution labels on the packages or do not have access to the protective gear specified for use with the pesticide. Therefore, many incidences of acute poisoning occur each year. In most cases, the symptoms disappear after a period free from exposure. Estimates of the number of poisonings are very difficult to obtain, since many go unreported, but in the United States, pesticide poisonings requiring medical treatment are in the thousands per year. The World Health Organization estimates that each year, there are between 1 million and 5 million acute pesticide poisonings and that about 20,000 deaths occur from pesticide poisonings.

For most people, however, the most critical health problem related to pesticide use is inadvertent exposure to very small quantities of pesticides. Many pesticides have been proven to cause mutations, produce cancers, or cause abnormal births in experimental animals. Studies of farmers who were occupationally exposed to pesticides over many years show that they have higher levels of certain kinds of cancers than the general public.

TABLE 14.1 **Insecticide Resistance of Houseflies to the Insecticide Cyfluthrin**

	Houseflies from a Susceptible Population	Houseflies from a Poultry Facility Population		
Concentration (ng/cm^2)	8.3	8.3 (1×)	83 (10×)	830 (100×)
Percent survival	0	100	90	38

Source: Data from Scott, Jeffrey G., et al., "Insecticide Resistance in Houseflies from Caged-Layer Poultry Facilities," *Pest Management Science* 56 (2000): 147–153.

There also are questions about the effects of chronic, minute exposures to pesticide residues in food or through contamination of the environment.

Following the rapid advance of modern agriculture in developed countries, developing countries have, over the past half century, increasingly adopted a pest management approach that centers on the use of chemical pesticides. The pesticide world market's total value surpasses US $26 billion. Developing countries' share of this is approximately one-third. It is reasonable to expect that developing countries will experience the same kinds of health problems and environmental side effects that led industrialized countries to develop pesticide-regulating laws in the 1970s.

A variety of factors is likely to make people in developing countries—especially farmers and agricultural workers—more vulnerable to the toxicological effects of pesticides. These include:

- Low literacy and education levels
- Weak or absent legislative and regulatory frameworks
- Climate factors (which make the use of protective clothing while spraying pesticides uncomfortable)
- Inappropriate or faulty spraying technology
- Lower nutritional status (weaker physiological defenses against toxic substances)

The first four of these factors increase the likelihood of higher exposure; the last factor increases the toxic effects from that exposure on the human body. In addition, it has been found that when pesticides are banned or restricted, people in developing countries have often turned to substances that exhibit even higher toxicity.

Although the risks of endangering health by consuming tiny amounts of pesticides are very small compared to other risk factors, such as automobile accidents, smoking, or poor eating habits, many people find pesticides unacceptable and seek to prohibit their sale and use. The U.S. Environmental Protection Agency requires careful studies of the effectiveness and possible side effects of each pesticide licensed for use. It has banned several pesticides from further use because new information suggests that they are not as safe as originally thought. For example, it banned the use of dinoseb, an herbicide, because tests by the German chemical company Hoechst AG indicated that dinoseb causes birth defects in rabbits. Other studies indicate that dinoseb causes sterility in rats. Similarly, in 1987, Velsicol Chemical Corporation signed an agreement with the EPA to stop producing and distributing chlordane in the United States. Chlordane had been banned previously for all applications except for termite control. After it was shown that harmful levels of chlordane could exist in treated homes, its use was finally curtailed. Also in 1987, the Dow Chemical Company announced that it would stop producing the controversial herbicide 2,4,5-T. In both of these cases, new pesticides were developed to replace the older types, so that discontinuing them did not result in an economic hardship for farmers or other consumers.

Finally, during the 1990s, the EPA required that many pesticides be reregistered. During this process, manufacturers needed to justify the continued production of the product. In many cases, companies simply did not want to spend the money to go through the registration process; therefore, the product was withdrawn from the market. In other cases, the variety of uses was modified. For example, chlorpyrifos, one of the most widely used insecticides, had its use altered. Through negotiations with the producers, its use in homes and schools will be eliminated, while it will still be used in most agricultural settings.

WHY ARE PESTICIDES SO WIDELY USED?

Figure 14.10 shows changes in the use of pesticides throughout the world. Use is projected to continue to increase significantly. If pesticides have so many drawbacks, why are they used so extensively? There are three primary reasons. First, the use of pesticides has increased, at least in the short term, the amount of food that can be grown in many parts of the world. In the United States, pests are estimated to consume 33 percent of the crops grown. On a worldwide basis, pests consume approximately 35 percent of crops. This represents an annual loss of $18.2 billion in the United States alone. Farmers, grain-storage operators, and the food industry continually seek to reduce this loss. A retreat from dependence on pesticides would certainly reduce the amount of food produced. Agricultural planners in most countries are not likely to suggest changes in pesticide use that would result in malnutrition and starvation for many of their inhabitants.

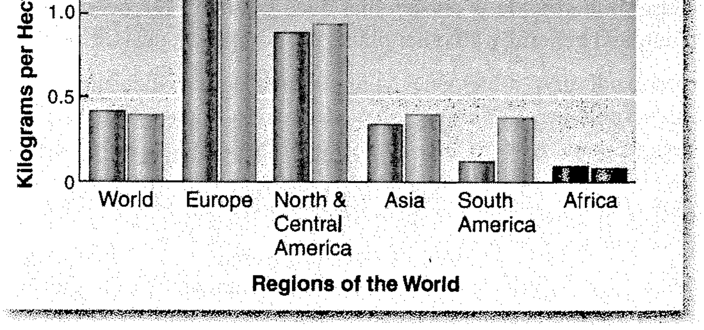


FIGURE 14.10 Changes in Pesticide Use The use of pesticides is greatest in the developed world, comprising about 67 percent of the total. However, all parts of the world except Europe are experiencing increased use of pesticides. The use in Africa is low and relatively stable.
Source: Data from Food and Agriculture Organization of the United Nations.

Going Green

Organic Farming: Helping to Promote Sustainable Agriculture

Organic food is more than a trendy industry that provides healthful produce to co-ops and upscale markets. Sustainable agriculture can help fight world hunger and some of its related challenges, including a shrinking safe water supply and pesticide contamination. This news comes at a critical time for reasons such as the following:

- The majority of the people who are chronically hungry in the world are small-scale farmers and their families who depend on the land to give them the food they need to survive.
- In many regions where hunger is a major problem, water for agriculture is also scarce.
- Pesticides used in conventional farming get into bodies of water, suffocate aquatic plants and animals, and accumulate in the food chain, eventually contaminating plants and animals that are consumed by humans and throwing off the environmental balance.

Sustainable agriculture methods, which include organic farming and crop rotation, are providing satisfying results for many small-scale farmers around the world. According to the United Nations, in 57 of the world's poorest regions, small-scale farmers who use sustainable agriculture techniques have increased their yields by 71 percent. These farmers are experiencing other benefits:

- Because farmers who practice sustainable agriculture methods use few or no pesticides, they can avoid that expense.
- Organic farming also requires less water, because soils that are high in organic material are much more efficient at holding water than is poorer soil. High-quality soil is better able to deal with drought conditions, a major consideration in many impoverished nations, especially in Africa.
- Organic farming is often more labor intensive than conventional farming, especially in the beginning stages. However, because organic farming typically involves crop rotation throughout the year, farmers have more evenly distributed planting and harvesting schedules and better distribution of labor.
- Crop rotation spreads out the risk of crop failure; it can also make farmers more competitive in the marketplace if they sell some of their produce. It also provides farmers and their families with a more nutritious and varied diet.

The economic value of pesticides is the second reason they are used so extensively. The cost of pesticides is more than offset by increased yields and profits for the farmer. In addition, the production and distribution of pesticides is big business. Companies that have spent millions of dollars developing a pesticide are going to argue very strongly for its continued use. Since farmers and agrochemical interests have a powerful voice in government, they have successfully lobbied for continued use of pesticides.

A third reason for extensive pesticide use is that many health problems are currently impossible to control without insecticides. This is particularly true in areas of the world where insect-borne diseases would cause widespread public health consequences if insecticides were not used.

ALTERNATIVES TO CONVENTIONAL AGRICULTURE

Before the invention of synthetic fertilizers, herbicides, fungicides, and other agrochemicals, animal manure and crop rotation provided soil nutrients; a mixture of crops prevented regular pest problems; and manual labor killed insects and weeds. With the development of mechanization, larger areas could be farmed, draft animals were no longer needed, and many farmers changed from mixed agriculture, in which animals were an important ingredient, to monoculture. Chemical fertilizers replaced manure as a source of soil nutrients, and crop rotation was no longer as important, since hay and grain were no longer grown for draft animals and cattle. The larger fields of crops such as corn, wheat, and cotton presented opportunities for pest problems to develop, and chemical pesticides were used to "solve" this problem.

Today, many people feel current agricultural practices are not sustainable and that we should look for ways to reduce reliance on fertilizer and pesticides, while ensuring good yields and controlling the pests that compete with us for the food that we raise. Several alternative approaches have somewhat different but overlapping goals. Some of the terms used to describe these approaches are: *alternative agriculture, sustainable agriculture,* and *organic agriculture.* **Alternative agriculture** is the broadest term. It includes all nontraditional agricultural methods and encompasses sustainable agriculture, organic agriculture, alternative uses of traditional crops, alternative methods for raising crops, and producing crops for industrial use. The **sustainable agriculture** movement maintains that current practices are degrading natural resources and seeks methods to produce adequate, safe food in an economically viable manner while enhancing the health of agricultural land and related ecosystems.

Sustainable Agriculture

There has been a growing interest in sustainable agriculture. There has also been a growing amount of misleading information surrounding sustainable agriculture. In recent decades, sustainable

farmers and researchers around the world have responded to the extractive industrial model with ecology-based approaches, variously called natural, organic, low-input, alternative, regenerative, holistic, biodynamic, biointensive, and biological farming systems. All of them, representing thousands of farms, have contributed to our understanding of what sustainable systems are, and all share a vision of "farming with nature" and agro-ecology that promotes biodiversity, recycles plant nutrients, protects soil erosion, conserves and protects water, uses minimum tillage, and integrates crop and livestock enterprises on the farm.

But no matter how elegant the system or how accomplished the farmer, no agriculture is sustainable it it's not also profitable and able to provide a healthy family income and a good quality of life. Sustainable practices lend themselves to smaller, family-scale farms. These farms, in turn, tend to find their best niches in local markets, within local food systems, often selling directly to consumers. As alternatives to industrial agriculture evolve, so must their markets and the farmers who serve them. Creating and serving new markets remains one of the key challenges for sustainable agriculture.

Sustainable agriculture is a method of agriculture that does not deplete soil, water, air, wildlife, or human community resources. Sustainable agriculture is a term used globally to refer to farming practices that strive for this ideal as opposed to methods that rely heavily on products such as gasoline, chemical fertilizers, and pesticides. A growing number of farmers throughout the world are growing all of the major food groups (grains, dairy, meat, vegetables, fruit) using sustainable methods. Though yields differ by crop and growing region, in general, sustainable methods do achieve average yields.

There are many different types of sustainable pest and weed control practices. They are, however, guided by some general principles. These include:

- Keeping insecticide, herbicide, fungicide, and fertilizer to a minimum.
- Biological diversity (many different types of plants and animals) should be encouraged.
- Healthy, biologically active soils lead to healthier, more insect- and disease-resistant plants and animals.
- Natural or supplemented populations of beneficial insects (good bugs) will keep pests (bad bugs) below economically damaging levels. Many sustainable farmers purposely grow plants that will attract beneficial insects.

Fertile soils have a balanced mix of minerals, organic matter, microorganisms, and macroorganisms (like earthworms). Sustainable farmers try to keep these components in balance by adding compost, minerals, and naturally occurring fertilizers (like bloodmeal or bat guano) and by plowing back into the soil crop residues or crops grown specifically for fertility.

Organic Food

Organically grown is a legally defined term in the United States that tells you how a food or fiber crop was grown. Thirty states also have their own legal definitions. The U.S. Federal Organic Foods Production Act of 1990 defines national organic standards, which generally:

- Require organic farms and organic handlers to be "certified," that is, inspected by a disinterested third party
- Require that an organic farm be increasing its soil fertility through sustainable soil-building techniques
- Prohibit synthetic pesticides and fertilizers

One concern about organically grown food is its cost to the consumer. While the cost of organic products can be more expensive, they can also be thought of as less expensive in the long run. The organic market, while growing, is still limited by low supply, so prices are higher than they might otherwise be. In addition, most organic food is produced by smaller farms that do not have the economics of large-scale industrial agribusiness. You can support sustainable agriculture by growing your own food in whatever space you have and by buying organic foods at food co-ops, natural food stores, or farmer markets. You can also ask your local supermarket to carry organic foods.

Techniques for Protecting Soil and Water Resources

In order to reduce the negative impacts of conventional agriculture while making a profit, farmers must deal with the twin problems of protecting the quality and fertility of the soil while controlling pests of their crops. A wide variety of techniques can be used to reduce the negative impact of conventional agricultural activity and maintain economic viability for the farmer.

Conventional farming practices have several negative effects on soil and water. Soil erosion is a problem throughout the world. (See chapter 13.) However, two other problems are also important: compaction of the soil and reduction in soil organic matter. Several changes in agricultural production methods can help to reduce these problems. Reducing the number of times farm equipment travels over the soil will reduce the degree of compaction. Leaving crop residue on the soil and incorporating it into the soil reduces erosion and increases soil organic matter. In addition, introducing organic matter into the soil makes compaction less likely.

Conventional agriculture has several negative impacts on watersheds: fertilizer runoff stimulates aquatic growth and degrades water resources; pesticides can accumulate in food chains; and groundwater resources can be contaminated by fertilizer, pesticides, or animal waste. Reducing or eliminating these sources of contamination would enhance ecological harmony and reduce a threat to human health. Fertilizer runoff can be lessened by reducing the amount of fertilizer applied and the conditions under which it is applied. Applying fertilizer as plants need it will ensure that more of it is taken up by plants and less runs off. Increased organic matter in the soil also tends to reduce runoff. More careful selection, timing, and use of pesticides would decrease the extent to which these materials become environmental contaminants.

Precision agriculture is a new technique that addresses many of these concerns. With modern computer technology and geographic information systems, it is now possible, based on the soil

and topography, to automatically vary the chemicals applied to the crop at different places within a field. Thus, less fertilizer is used, and it is used more effectively.

True organic agriculture that uses neither chemical fertilizers nor pesticides is the most effective in protecting soil and water resources from these forms of pollution, but it requires several adjustments in the way in which farming is done. Crop rotation is an effective way to enhance soil fertility, reduce erosion, and control pests. The use of nitrogen-fixing legumes, such as clover, alfalfa, beans, or soybeans, in crop rotation increases soil nitrogen but places other demands on the farmer. For example, it typically requires that cattle be a part of the farmer's operation in order to make use of forage crops and provide organic fertilizer for subsequent crops. Crop rotation also requires a greater investment in farm machinery, since certain crops require specialized equipment. Also, the raising of cattle requires additional expenditures for feed supplements and veterinary care. Critics say that organic farming cannot produce the amount of food required for today's population and that it can be economically successful only in specific cases. Proponents disagree and stress that when the hidden costs of soil erosion and pollution are included, organic agriculture or some modification of it is a viable alternative approach to conventional means of food production. Furthermore, organic farmers are willing to accept lower yields because they do not have to pay for expensive chemical fertilizers and pesticides. In addition, organic farmers often receive premium prices for products that are organically grown. Thus, even with lower yields, they can still make a profit.

Integrated Pest Management

Integrated pest management uses a variety of methods to control pests rather than relying on pesticides alone. Integrated pest management is a technique that depends on a complete understanding of all ecological aspects of the crop and the particular pests to which it is susceptible to establish pest control strategies. It requires information about the metabolism of the crop plant, the biological interactions between pests and their predators or parasites, the climatic conditions that favor certain pests, and techniques for encouraging beneficial insects. It may involve the selective use of pesticides. Much of the information necessary to make integrated pest management work goes beyond the knowledge of the typical farmer. The metabolic and ecological studies necessary to pinpoint weak points in the life cycles of pests can usually be carried out only at universities or government research institutions. These studies are expensive and must be completed for each kind of pest, since each pest has a unique biology. Once a viable technique has been developed, an educational program is necessary to provide farmers with the information they need in order to use integrated pest management rather than the "spray and save" techniques that they used previously and that pesticide salespeople continually encourage.

Several methods are employed in integrated pest management. These include disrupting reproduction, using beneficial organisms to control pests, developing resistant crops, modifying farming practices, and selectively using pesticides.

Disrupting Reproduction

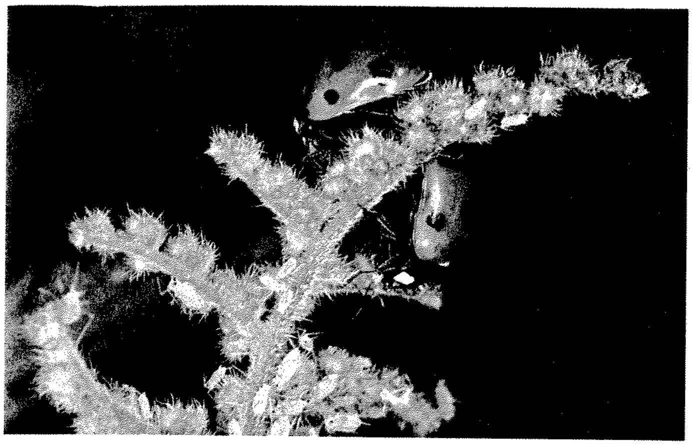
In some species of insects, a chemical called a **pheromone** is released by females to attract males. Males of some species of moths can detect the presence of a female from a distance of up to 3 kilometers (nearly 2 miles). Since many moths are pests, synthetic odors can be used to control them. Spraying an area with the pheromone confuses the males and prevents them from finding females, which results in a reduced moth population the following year. In a similar way, a synthetic sex attractant molecule known as Gyplure is used to lure gypsy moths into traps, where they become stuck. Since the females cannot fly and the males are trapped, the reproductive rate drops, and the insect population may be controlled.

Another technique that reduces reproduction is male sterilization. In the southern United States and Central America, the screwworm fly weakens or kills large grazing animals, such as cattle, goats, and deer. The female screwworm fly lays eggs in open wounds on these animals, where the larvae feed. However, it was discovered that the female mates only once in her lifetime. Therefore, the fly population can be controlled by raising and releasing large numbers of sterilized male screwworm flies. Any female that mates with a sterile male fails to produce fertilized eggs and cannot reproduce. In Curaçao, an island 65 kilometers (40 miles) north of Venezuela, a program of introducing sterile male screwworm flies eliminated this disease from the 25,000 goats on the island. In parts of the southwestern United States, the sterile male technique has also been very effective. The screwworm fly has been eliminated from the United States and northern Mexico, and much of Central America may become free of them as well. In 1990, sterile males were released in Libya to begin eliminating screwworm flies that had been introduced with a South American cattle shipment.

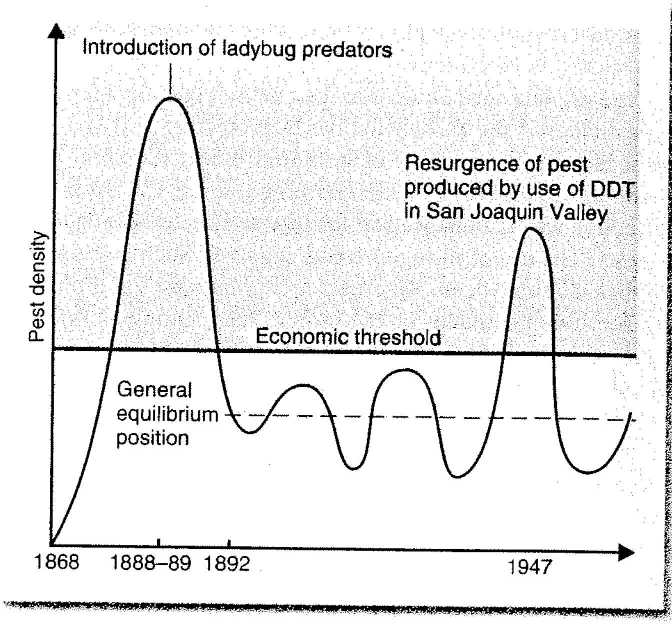
During an epidemic of Mediterranean fruitflies in southern California and northern Mexico in the early 1980s, a similar technique was employed. Unfortunately, the X-ray technique used to sterilize the males was ineffective, and most of the flies released were not sterile, which made the problem worse rather than better. Pesticides were eventually used to control the fruitflies. Recent concern about the Mediterranean fruitfly in California has resulted in the controversial aerial spraying of malathion.

Using Beneficial Organisms to Control Pests

The manipulation of predator-prey relationships can also be used to control pest populations. For instance, the ladybird beetle, commonly called a ladybug, is a natural predator of aphids and scale insects. (See figure 14.11a.) Artificially increasing the population of ladybird beetles reduces aphid and scale populations. In California during the late 1800s, scale insects on orange trees damaged the trees and reduced crop yields. The introduction of a species of ladybird beetle from Australia quickly brought the pests under control. Years later, when chemical pesticides were first used in the area, so many ladybird beetles were accidentally killed that scale insects once again became a serious problem. When pesticide use was discontinued, ladybird beetle populations rebounded, and the scale insects were once again brought under control. (See figure 14.11b.)



(a)

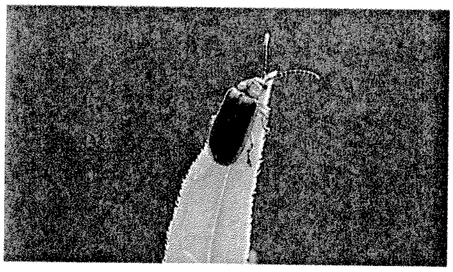


(b)

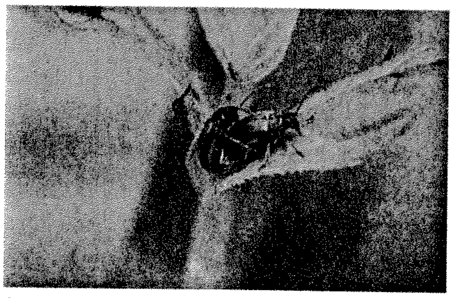
FIGURE 14.11 Insect Control with Natural Predators (a) The ladybird beetle is a predator of many kinds of pest insects, including aphids. (b) In 1889, the introduction of ladybird beetles (ladybugs) brought the cottony cushion scale under control in the orange groves of the San Joaquin Valley. In the 1940s, DDT reduced the ladybird beetle population, and the cottony cushion scale population increased. Stopping the use of DDT allowed the ladybird population to increase, reducing the pest population and allowing the orange growers to make a profit.

Source: (b) V. M.Stern, et al., *Hilgardia,* 29: 93, 1959.

(a) Purple loosestrife



(b) Galerucella calmariensis



(c) Galerucella pusilla

(d) Hylobius transversovittatus

FIGURE 14.12 Biological Control of Purple Loosestrife (a) Purple loosestrife is a European plant that invades wetlands and prevents the growth and reproduction of native species of plants. Several kinds of European beetles that feed on purple loosestrife have been released as biological control agents. (b, c) Two species (*Galerucella calmariensis* and *Galerucella pusilla*) feed on the leaves, shoots, and flowers of the newly growing purple loosestrife. (d) Another species (*Hylobius transversovittatus*) has larvae that feed on the roots. It appears that they are actually slowing the spread of purple loosestrife.

Herbivorous insects can also be used to control weeds. Purple loosestrife (*Lythrum salicaria*) is a wetlands plant accidentally introduced from Europe in the mid-1800s. It takes over sunny wetlands and eliminates native vegetation such as cattails, thereby eliminating many species that rely on cattails for food, nesting places, or hiding places. (See figure 14.12.) The plant exists in most states and provinces in the United States and Canada. In Europe, the plant is not a pest because there are several insect species that attack it in various stages of the plant's life cycle. Since purple loosestrife is a European plant, a search was made to identify candidate species of insects that would control it. The criteria were that the insects must live only on purple loosestrife and not infest other plants and must have the capacity to do major damage to purple loosestrife. Five species of beetles have been identified

that will attack the plant in various ways. After extensive studies to determine if introductions of these insects from Europe would be likely to cause other problems, several were selected as candidates to help control purple loosestrife in the United States and Canada. Some combination of these beetles has been released in a large proportion of the states and provinces infested with purple loosestrife. Two species (*Galerucella calmariensis* and *Galerucella pusilla*) feed on the leaves, shoots, and flowers of the newly growing purple loosestrife; one (*Hylobius transversovittatus*) has larvae that feed on the roots. Two other species (*Nanophyes brevis* and *Nanophyes marmoratus*) feed on the flowers. This multipronged attack by several species of beetles has been effective in reducing populations of purple loosestrife.

The use of specific strains of the bacterium *Bacillus thuringiensis* to control mosquitoes and moths is another example of the use of one organism to control another. A crystalline toxin produced by the bacterium destroys the lining of the gut of the feeding insect, resulting in its death. One strain of *B. thuringiensis* is used to control mosquitoes, while another is primarily effective against the caterpillars of leaf-eating moths, including the gypsy moth.

Naturally occurring pesticides found in plants also can be used to control pests. For example, marigolds are planted to reduce the number of soil nematodes, and garlic plants are used to check the spread of Japanese beetles.

Developing Resistant Crops

One outcome of the major advances in molecular genetics is the development of specialized organisms that have had specific, valuable genes inserted into their genetic makeup. Although this is a relatively new technology, it is an extension of an ancient art. Farmers have been involved in manipulating the genetic makeup of their plants and animals since these organisms were first domesticated. Initially, farmers either consciously or accidentally chose to plant specific seeds or breed certain animals that had specific desirable characteristics. This resulted in local varieties with particular characteristics. When the laws of genetics began to be understood in the early 1900s, scientists began to make precise crosses between carefully selected individuals to enhance the likelihood that their offspring would have certain highly desirable characteristics. This led to the development of hybrid seeds and specific breeds of domesticated animals. Controlled plant and animal breeding resulted in increased yields and better disease resistance in domesticated plants and animals. These activities are still the major driving force for developing improved varieties of domesticated organisms.

When the structure of DNA was discovered and it was determined that the DNA of organisms could be manipulated, an entirely new field of plant and animal breeding arose. **Genetic engineering** or **biotechnology** involves inserting specific pieces of DNA into the genetic makeup of organisms. The organism with the altered genetic makeup is known as a **genetically modified organism.** The DNA inserted could be from any source, even an entirely different organism. In agricultural practice, two kinds of genetically modified organisms have received particular attention. One involves the insertion of genes from a specific kind of bacterium called *Bacillus thuringiensis israeliensis* (Bti). Bti produces a material that causes the destruction of the lining of the gut of insects that eat it. It is a natural insecticide. To date, the gene has been inserted into the genetic makeup of several crop plants, including corn. In field tests, the genetically engineered corn was protected against some of its insect pests, but there was some concern that pollen grains from the corn might be blown to neighboring areas and affect nontarget insect populations. In particular, a study of monarch butterflies indicated that populations of butterflies adjacent to fields of this genetically engineered corn were negatively affected. One could argue that since the use of Bti corn results in less spraying of insecticides in cornfields, this is just a trade-off.

A second kind of genetically engineered plant involves inserting a gene for herbicide resistance into the genome of certain crop plants. The value of this to farmers is significant. For example, a farmer could plant cotton with very little preparation of the field to rid it of weeds. When both the cotton and the weeds began to grow, the field could be sprayed with a specific herbicide that would kill the weeds but not harm the herbicide-resistant cotton. This has been field-tested and it works. Critics have warned that the genes possibly could escape from the crop plants and become part of the genome of the weeds that we are trying to control, thus creating superweeds.

Many groups oppose the use of genetically modified organisms. They argue that this technology is going a step too far, that no long-term studies have been done to ensure their safety, that there are dangers we cannot anticipate, and that if such crops are grown, they should be labeled so that the public knows when they are consuming products from genetically modified organisms. The European Union (EU) will not buy genetically modified grains from the United States. This has resulted in farmers having to segregate their stores of grains so that they can guarantee to an EU buyer that a crop is not genetically modified and at the same time sell a genetically modified crop to other buyers.

Supporters argue that all plant and animal breeding involves genetic manipulation and that this is just a new kind of genetic manipulation. A great deal of evidence exists that genes travel between species in nature and that genetic engineering simply makes a common, natural process more frequent. Over the next 20 to 30 years, scientists hope to use biotechnology to produce high-yield plant strains that are more resistant to insects and disease, thrive on less fertilizer, make their own nitrogen fertilizer, do well in slightly salty soils, withstand drought, and use solar energy more efficiently during photosynthesis. These new kinds of genetically modified organisms will continue to be developed and tested, and the political arguments about their appropriateness will continue as well.

Modifying Farming Practices

Modification of farming practices can often reduce the impact of pests. In some cases, all crop residues are destroyed to prevent insect pests from finding overwintering sites. For example, shredding and plowing under the stalks of cotton in the fall reduces overwintering sites for boll weevils and reduces their

numbers significantly, thereby reducing the need for expensive insecticide applications. Many farmers are also returning to crop rotation, which tends to prevent the buildup of specific pests that typically occurs when the same crop is raised in a field year after year.

Selective Use of Pesticides

Pesticides can also play a part in integrated pest management. Identifying the precise time when the pesticide will have the greatest effect at the lowest possible dose has these advantages: It reduces the amount of pesticide used and may still allow the parasites and predators of pests to survive. Such precise applications often require the assistance of a trained professional who can correctly identify the pests, measure the size of the population, and time pesticide applications for maximum effect. In several instances, pheromone-baited traps capture insect pests from fields, and an assessment of the number of insects caught can be a guide to when insecticides should be applied.

Integrated pest management will become increasingly popular as the cost of pesticides rises and knowledge about the biology of specific pests becomes available. However, as long as humans raise crops, there will be pests that will outwit the defenses we develop. Integrated pest management is just another approach to a problem that began with the dawn of agriculture.

GENETICALLY MODIFIED CROPS

Genetically modified (GM) foods have attracted intense media coverage in recent years. Depending on one's point of view, they have been hailed as "super foods" or reviled as "frankenfoods." Yet, despite the controversy, GM foods have found their way onto dining tables. In the United States, an estimated 60 percent of processed foods in supermarkets—from breakfast cereals to softdrinks—contain a GM ingredient, such as soy, corn, or canola.

Selective plant breeding is not a new concept. Casual selection of observed desirable traits by our ancestors essentially tamed wild plants and made them suitable for agriculture. In the past, if pests devastated a field of crops and a few plants stayed alive and healthy, the seeds from these healthy plants were used to generate the next crop. Thus the beneficial factors that made the plants resistant were transferred to the next generation, making the new generation of crops slightly more resistant to the same pests. Such selections have been used for over 10,000 years, since the beginning of agriculture, and have resulted in significant advances for humanity with increased yields, disease resistance, and, overall, greater productivity. A good example is corn; the original crop was Teosinte with very small seeds and very few seeds in each cob. Over the centuries people selected for various traits, thus improving the size of the corn kernel, the number of kernels in each cob, and the stronger attachment of the kernels to the cob so that it could be harvested, resulting in the corn that we are familiar with today.

The advent of genetic engineering greatly enhanced this process of transferring a beneficial trait into plants by directly transferring the gene or genes responsible for the beneficial attribute. (See table 14.2.) So in one generation, or one planting season, a plant can be created that is the same in all respects except for the addition of the beneficial trait. Since genes in all living organisms code for similar proteins and properties, it is possible to transfer a gene from one good corn variety to another corn variety or from fish to strawberry plants.

TABLE 14.2 List of Genetically Modified Crops and Their Altered Traits

Modified Trait	Crop
Input Traits	
Herbicide resistance	Sugar beet, soybean, corn, canola, cotton, flax
Insect/herbicide resistance	Corn
Insect resistance	Tomato, corn, potato, cotton
Virus resistance	Squash, papaya
Male sterile	Corn
Output Traits	
Modified oil	Soybean, canola
Modified fruit ripening	Tomato
Provitamin A enriched	Rice
Iron fortification	Rice
Beta-carotene, lycopene enriched	Tomato
Detoxification of mycotoxins	Corn
Detoxification of cyanogens	Cassava
Caffeine-free	Coffee beans
Vitamin E enriched	Canola

Source: USDA.

We can now define a genetically modified organism: It is any organism that has been modified by altering one or more genes by recombinant techniques. A recombinant technique is the method used to transfer a gene of interest from one organism to another. A genetically modified food therefore is any food that is produced from plants or animals that have been genetically altered using this method.

The first genetically altered plant created was a tobacco plant with resistance to antibiotics in 1983. It was almost 10 years later when the first commercial genetically altered crop, a delayed-ripening tomato, "Flavr-savr," was commercially released.

Genetically altered foods are prevalent in the United States and the Western world. More than 60 percent of the foods we purchase from the supermarket today have ingredients derived from genetically modified crops. Most of these are either from corn or soybeans, which are the bases for numerous ingredients manufactured for the food industry, including starch, oils, proteins, and other ingredients. Despite this prevalence, a U.S. Department of Agriculture consumer focus group survey revealed that most consumers were unaware of the use of biotechnology in foods. Furthermore, the benefits of biotechnology were viewed as skewed toward producers and manufacturers, with little benefit to

the consumer. There was also skepticism about the long-term health effects and the environmental impact of genetically altered foods. It is therefore essential that we disseminate the information about genetic engineering so that we can have an informed debate on the merits and shortcomings of this technology.

Like all new technologies, the potential for applications is tremendous. Many of them must wait until they can be done more efficiently or more economically, or until their effects are better understood. Recently scientists created a genetically altered variety of rice, termed "golden rice," that contains higher levels of beta-carotene, a precursor for vitamin A. This is promising, considering that rice is the staple food for more than half the population of the world, many of whom are under- or malnourished. The future of the technology holds promise in a number of different ways:

1. Produce more food economically by improving yields and agricultural practices associated with farming.
2. Improve the nutritional quality of foods and enhance the levels of compounds that confer health benefits.
3. Improve the shelf life and quality of fresh fruits and vegetables.
4. Decrease allergenic compounds in foods such as peanuts and wheat.
5. Create crops that can be used to provide vaccines and other medical benefits.
6. Convert toxic soils into more productive land for agriculture.

The scope of the technology at the present time is only limited by our imagination, and its adoption must be a result of acceptance by the public at large.

The United States accounts for over two-thirds of all geneti cally modified crops planted globally. (See figure 14.13.) GM foo crops grown by U.S. farmers include corn, cotton, soybeans canola, squash, and papaya. Other major producers of GM crop are Argentina, which plants primarily genetically modifie soybeans, and Canada, whose principal genetically modified cro is canola.

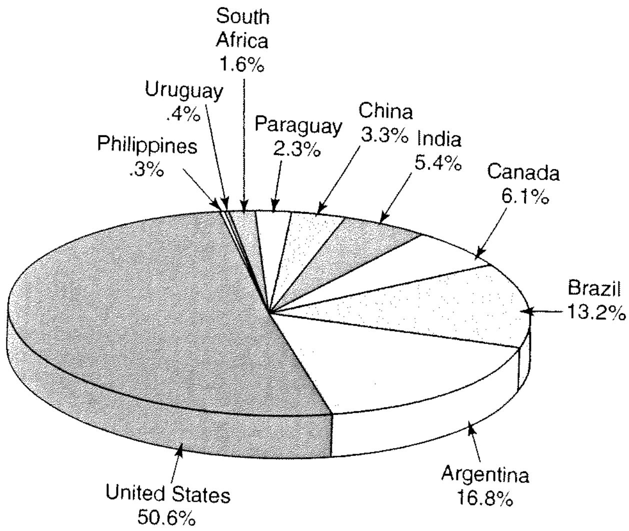


FIGURE 14.13 Global distribution of genetically modified crop land area.

SUMMARY

Although small slash-and-burn garden plots are common in some parts of the world, most of the food in the world is raised on more permanent farms. In countries where population size is high and money is in short supply, much of the farming is labor-intensive, using human labor for many of the operations necessary to raise crops. However, much of the world's food is grown on large, mechanized farms that use energy rather than human muscle for tilling, planting, and harvesting crops, and for producing and applying fertilizers and pesticides.

Monoculture involves planting large areas of the same crop year after year. This causes problems with plant diseases, pests, and soil depletion. Although chemical fertilizers can replace soil nutrients that are removed when the crop is harvested, they do not replace the organic matter necessary to maintain soil texture, pH, and biotic richness.

Mechanized monoculture depends heavily on the control of pests by chemical means. Persistent pesticides are stable and persist in the environment, where they may biomagnify in ecosystems. Consequently, many of the older persistent pesticides have been quickly replaced by nonpersistent pesticides that decompose much more quickly and present less of an environmental hazard. However, most nonpersistent pesticides are more toxic to humans and must be handled with greater care than the older persistent pesticides.

Pesticides can be divided into several categories based on the organism they are used to control. Insecticides are used to control insects, herbicides are used for plants, fungicides for fungi, and rodenticides for rodents. Because of the problems of persistence, biomagnification, resistance of pests to pesticides, and effects on human health, many people are seeking pesticide-free alternatives to raising food. Several different philosophies that seek the same ends—less use of chemicals and better stewardship of soil—are alternative agriculture, sustainable agriculture, and organic agriculture. One ingredient in all of these approaches is the use of integrated pest management, which employs a complete understanding of an organism's ecology to develop pest-control strategies that use no or few pesticides.

ISSUES & ANALYSIS

What Does "Certified Organic" Food Mean?

"Certified organic" refers to agricultural products that have been grown and processed according to uniform standards and verified by independent state or private organizations accredited by the USDA. All products sold as "organic" must be certified. Certification includes annual submission of an organic system plan and inspection of farm fields and processing facilities. Inspectors verify that organic practices such as long-term soil management, buffering between organic farms and neighboring conventional farms, and recordkeeping are being followed. Processing inspections include review of the facility's cleaning and pest control methods, ingredient transportation and storage, and recordkeeping and audit control. Organic foods are minimally processed to maintain the integrity of food without artificial ingredients or preservatives. Certified organic requires the rejection of synthetic agrochemicals, irradiation, and genetically engineered foods or ingredients. Since 2002, organic certification in the United States has taken place under the authority of the USDA National Organic Program, which accredits organic certifying agencies and oversees the regulatory process. To find out more about the national organic certification requirements and organic program, please go to the USDA National Organic Program website at www.arms.usda.gov/nop.

Organic Crops	Organic Livestock	Organic Labels
Land must not have prohibited substances applied to it for at least three years.	Animals for slaughter must be raised under organic management from the last third of gestation, or no later than the second day of life for poultry.	Foods labeled "100 percent organic" and "organic" must contain (excluding water and salt) only organically produced ingredients.
Use of genetic engineering, ionizing radiation, and sewage sludge is prohibited.	Livestock must be fed products that are 100 percent organic. Vitamin and mineral supplements are permitted.	Products labeled "organic" must consist of at least 95 percent organically produced ingredients (excluding water and salt).
No chemical fertilizer can be used. Only animal and crop wastes and tillage methods may be used to provide fertility.	No antibiotics or hormones may be used.	Processed products that contain at least 70 percent organic ingredients can use the phrase "made with organic ingredients."
Synthetic pesticides must not be used, but pesticides made from plants and other natural sources may be used.	Animal welfare conditions require that: 1. Animals have access to the outdoors. (They may be temporarily confined only for reasons of health, safety, the animal's stage of production, or protection of soil or water quality.) 2. Preventive health management practices must be employed, including the use of vaccines to keep animals healthy. 3. Sick or injured animals must be treated; however, animals treated with a prohibited medication may not be sold as organic.	Processed products that contain less than 70 percent organic ingredients cannot use the term *organic* anywhere on the label but may list the ingredients that are organic.
Farms and handling operations that sell less than $5,000 annually of organic agricultural products are exempt from certification. But if they comply with all other national standards for organic products, they may label their products as organic.	A dairy herd can be converted to organic production if 80 percent organically produced feed is used for nine months, followed by three months of 100 percent organically produced feed.	Products with pesticide residues up to 5 percent of the EPA pesticide tolerance may be sold as organic.

- Many people feel there is no difference in food quality between foods that are labeled organic and those that are not. Do you think the nutritional quality of organic foods differs from that of conventionally produced foods?
- The rules permit small amounts of pesticide residues. Why do you think these are allowed?
- The rule that animals must have access to the outdoors has been challenged. Do you think being outdoors changes the quality of the meat, milk, or eggs produced?

Thinking Green

1. Reduce or eliminate the use of pesticides and herbicides on your yard or garden.
2. Support local or regional producers of sustainable agricultural products.
3. Visit your local "farmers market."
4. Visit a grocery store and identify the origins of three fruits. How far did they travel to get to the store?
5. Plant your own organic garden even if it is only a small container in your apartment.

What's Your Take?

In 2006, a U.S. court of appeals upheld a ban on phosphorus use in lawn fertilizers in Madison, Wisconsin. The ban was originally enacted in 2004 to reduce the amount of phosphorus runoff into Madison's lakes and diminish the algae blooms that plague the lakes each summer. Fertilizer manufacturers appealed the ban, claiming that local government could not regulate the fertilizers, since state law controls the use of pesticides and local law cannot supersede state law. The court of appeals rejected this argument, stating that the "weed and feed" products are a fertilizer-pesticide mixture, and that since local governments can regulate fertilizers, the combination can be regulated by local ordinances. Develop a position paper that supports or refutes the court of appeals ruling.

Review Questions

1. What is monoculture?
2. List three reasons why fossil fuels are essential for mechanized agriculture.
3. Describe why pesticides are commonly used in mechanized agriculture.
4. Why are fertilizers used? What problems are caused by fertilizer use?
5. How do persistent and nonpersistent pesticides differ?
6. What is biomagnification? What problems does it cause?
7. How do organic farms differ from conventional farms?
8. Name three nonchemical methods of controlling pest populations.
9. What are the advantages and disadvantages of integrated pest management?
10. List three uses of food additives.
11. List three actions farmers could take to reduce the effect of pesticides on the environment.

Critical Thinking Questions

1. If you were a public health official in a developing country, would you authorize the spraying of DDT to control mosquitoes that spread malaria? What would be your reasons?
2. Look at table 14.1. What caused the changes in the effectiveness of the insecticide? If you were an agricultural extension agent, what alternatives to pesticides might you recommend?
3. Imagine that you are a scientist examining fish in Lake Superior and you find toxaphene in the fish you are studying. Toxaphene was used primarily in cotton farming and has been banned since 1982. How can you explain its presence in these fish?
4. Are the risks of pesticide use worth the benefits? What values, beliefs, and perspectives lead you to this conclusion?
5. Do you think that current agricultural practices are sustainable? Why or why not? What changes in agriculture do you think will need to happen in the next 50 years?
6. Imagine you are an EPA official who is going to make a recommendation about whether an agricultural pesticide can remain on the market or should be banned. What are some of the facts you would need to make your recommendation? Who are some of the interest groups interested in the outcome of your decision? What arguments might they present regarding their positions? What political pressures might they be able to bring to bear on you?
7. Why are few consumers demanding alternative methods of crop production, and why are farmers not using those methods?